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**Shrestha et al.**

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(45) **Date of Patent: Sep. 1, 2020**

(54) **METHODS TO HANDLE SCHEDULING REQUESTS FOR ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC) IN NEW RADIO (NR) SYSTEMS**

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**Related U.S. Application Data**

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(51) **Int. Cl.**

| | |
|---|---|
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| ***H04W 80/02*** | (2009.01) |
| ***H04W 72/10*** | (2009.01) |
| ***H04W 76/27*** | (2018.01) |
| ***H04W 72/12*** | (2009.01) |
| ***H04W 28/02*** | (2009.01) |
| ***H04W 72/14*** | (2009.01) |

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(52) **U.S. Cl.**

CPC ..... ***H04W 88/06*** (2013.01); ***H04L 5/00*** (2013.01); ***H04W 28/0278*** (2013.01); ***H04W 72/10*** (2013.01); ***H04W 72/1242*** (2013.01); ***H04W 72/1284*** (2013.01); ***H04W 72/14*** (2013.01); ***H04W 76/27*** (2018.02); ***H04W 80/02*** (2013.01); *H04W 72/042* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 2010/0034147 | A1* | 2/2010 | Ho | H04L 1/18 370/328 |
| 2018/0014322 | A1* | 1/2018 | Loehr | H04W 76/28 |

OTHER PUBLICATIONS

3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Medium Access Control (MAC) protocol specification; 3GPP TS 38.321 V15.0.0 (Dec. 2017) (Year: 2017).*

* cited by examiner

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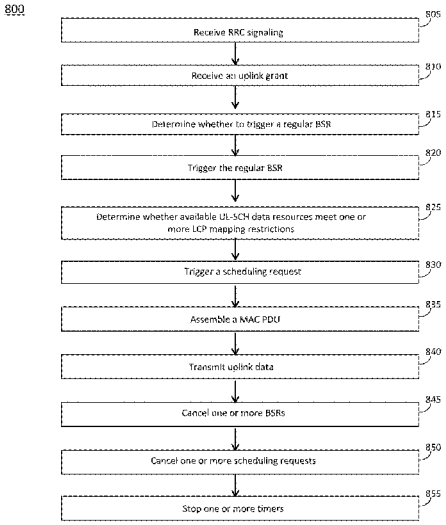
(57) **ABSTRACT**

Embodiments of a User Equipment (UE) and methods of communication are generally described herein. The UE may, if a regular buffer status report (BSR) is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available uplink shared channel (UL-SCH) data resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for a logical channel of uplink data: trigger a scheduling request to request UL-SCH data resources for a new transmission of uplink data. Currently pending SRs and BSRs may not be cancelled after assembly of a medium access control (MAC) protocol data unit (PDU), but may be cancelled at a later time when a MAC PDU including a BSR is transmitted.

**20 Claims, 14 Drawing Sheets**



(51) **Int. Cl.**
***H04L 5/00*** (2006.01)
*H04W 72/04* (2009.01)

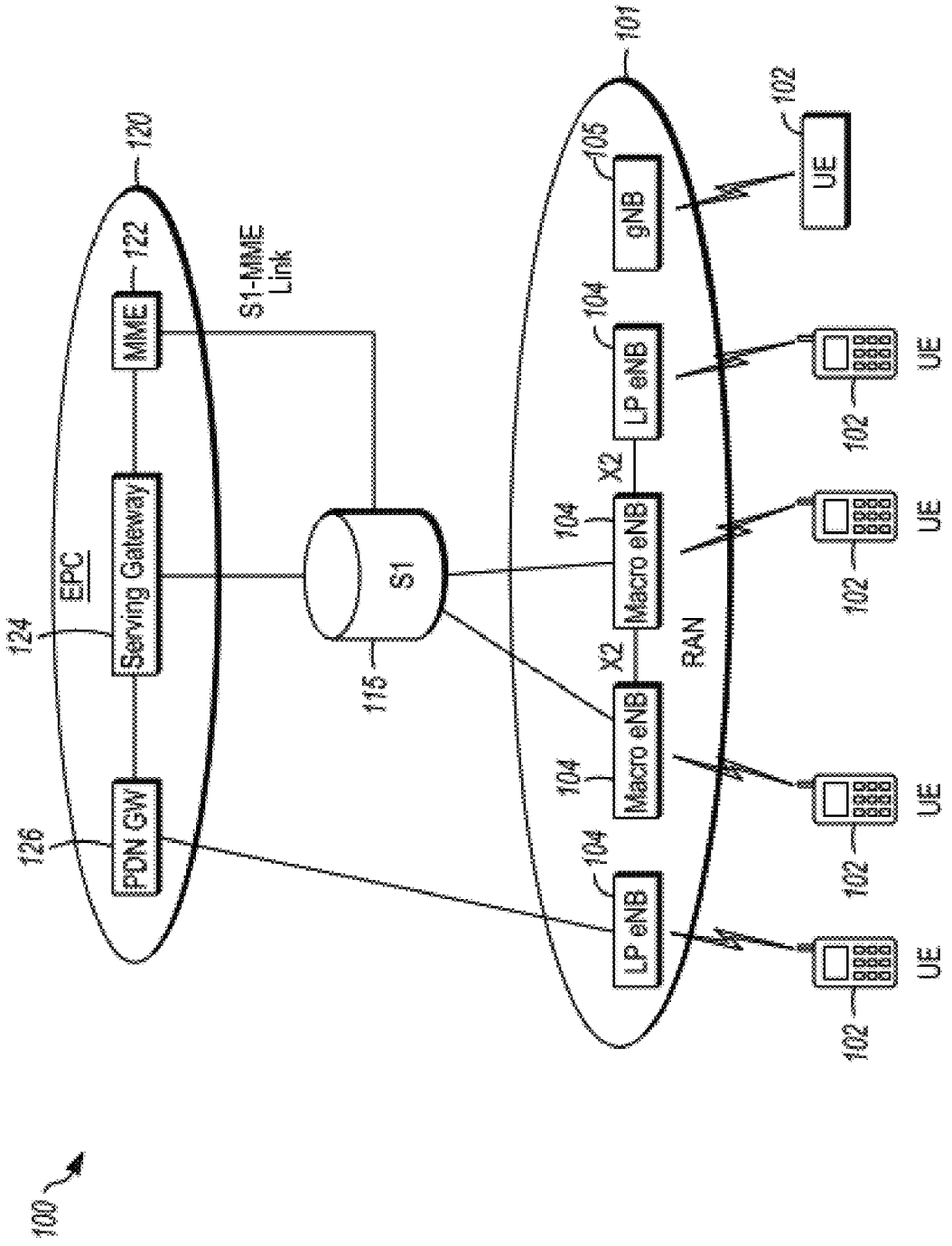

100
101
120
122
MME
S1-MME Link
EPC
124
Serving Gateway
PDN GW
126
S1
115
105
gNB
UE
102
104
LP eNB
X2
Macro eNB
RAN

FIG. 1A

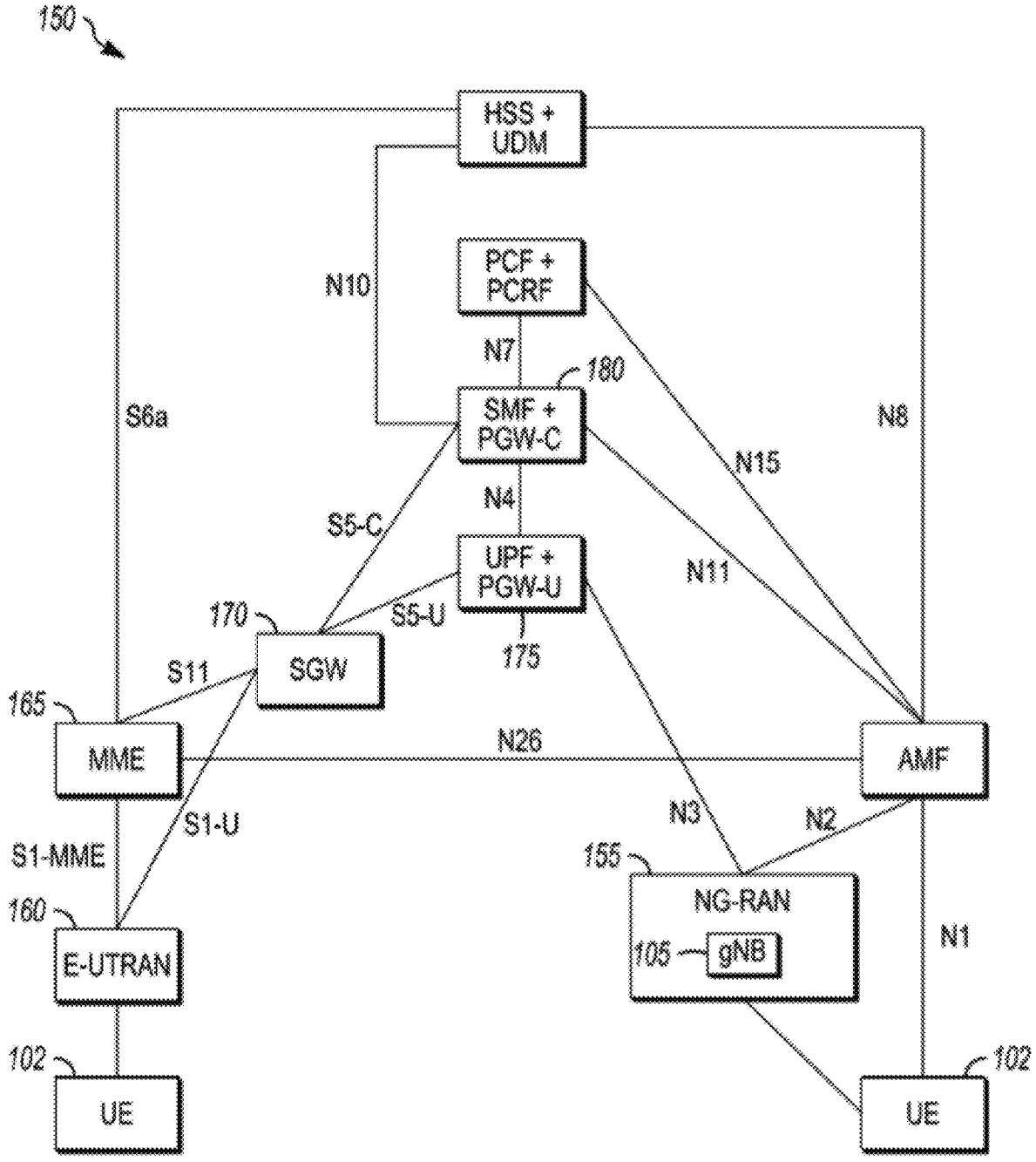

150
HSS + UDM
PCF + PCRF
N10
N7
180
SMF + PGW-C
S6a
N8
N15
N4
S5-C
UPF + PGW-U
N11
170
S5-U
175
S11
SGW
165
MME
N26
AMF
S1-U
N3
N2
S1-MME
155
NG-RAN
160
105
gNB
N1
E-UTRAN
102
102
UE
UE

FIG. 1B

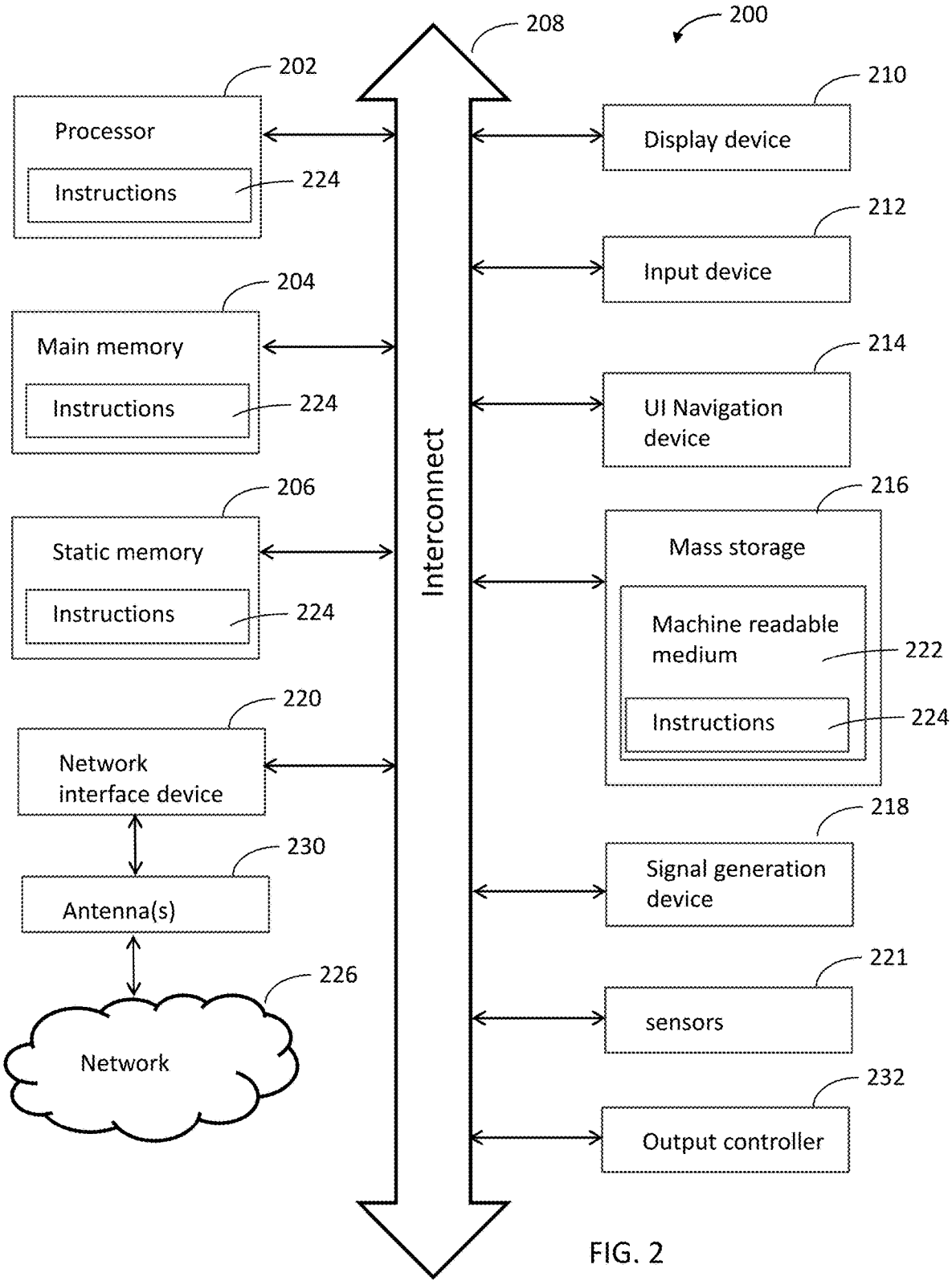

200
208
Interconnect
202
Processor
Instructions
224
204
Main memory
Instructions
224
206
Static memory
Instructions
224
220
Network interface device
230
Antenna(s)
226
Network
210
Display device
212
Input device
214
UI Navigation device
216
Mass storage
Machine readable medium
222
Instructions
224
218
Signal generation device
221
sensors
232
Output controller

FIG. 2

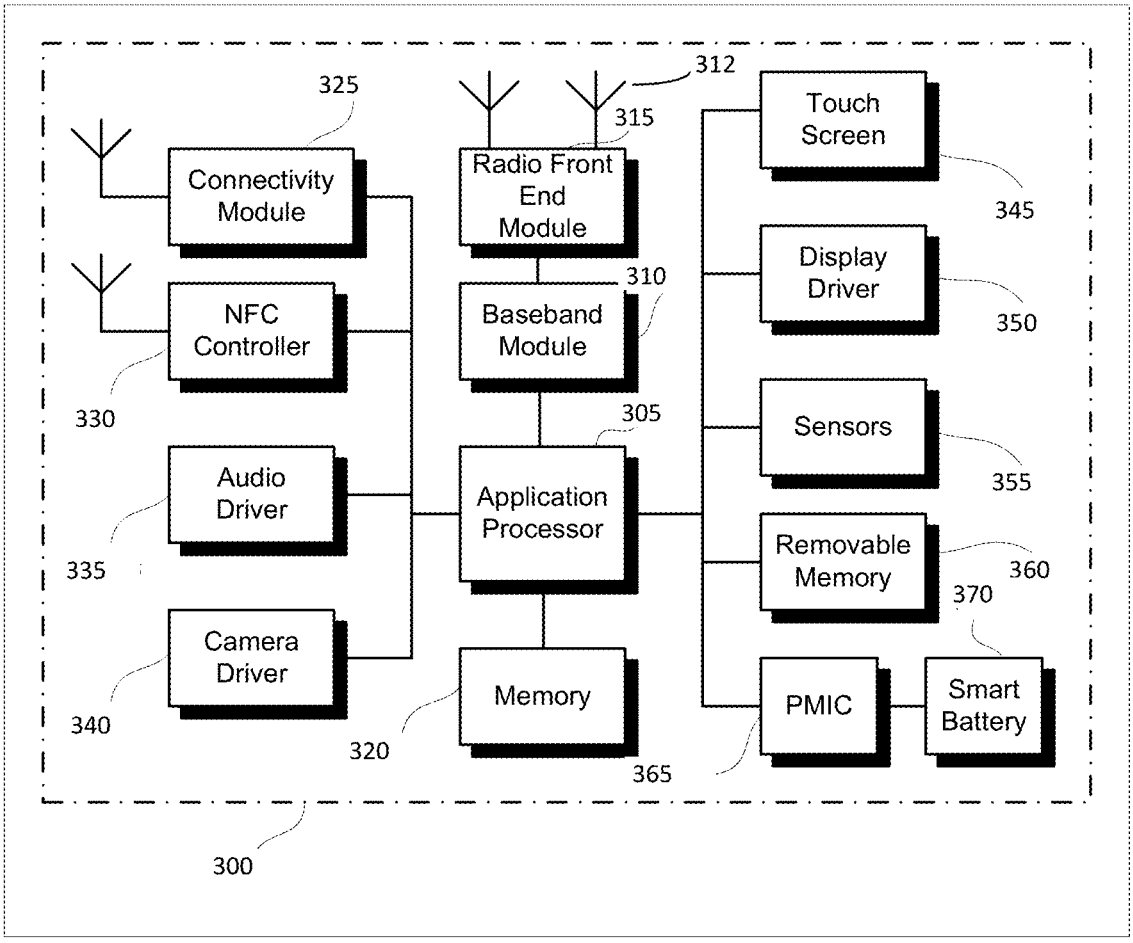

325
312
315
Connectivity Module
Radio Front End Module
Touch Screen
345
NFC Controller
330
Baseband Module
310
Display Driver
350
Sensors
355
305
Audio Driver
335
Application Processor
Removable Memory
360
370
Camera Driver
340
Memory
320
PMIC
Smart Battery
365
300

FIG. 3

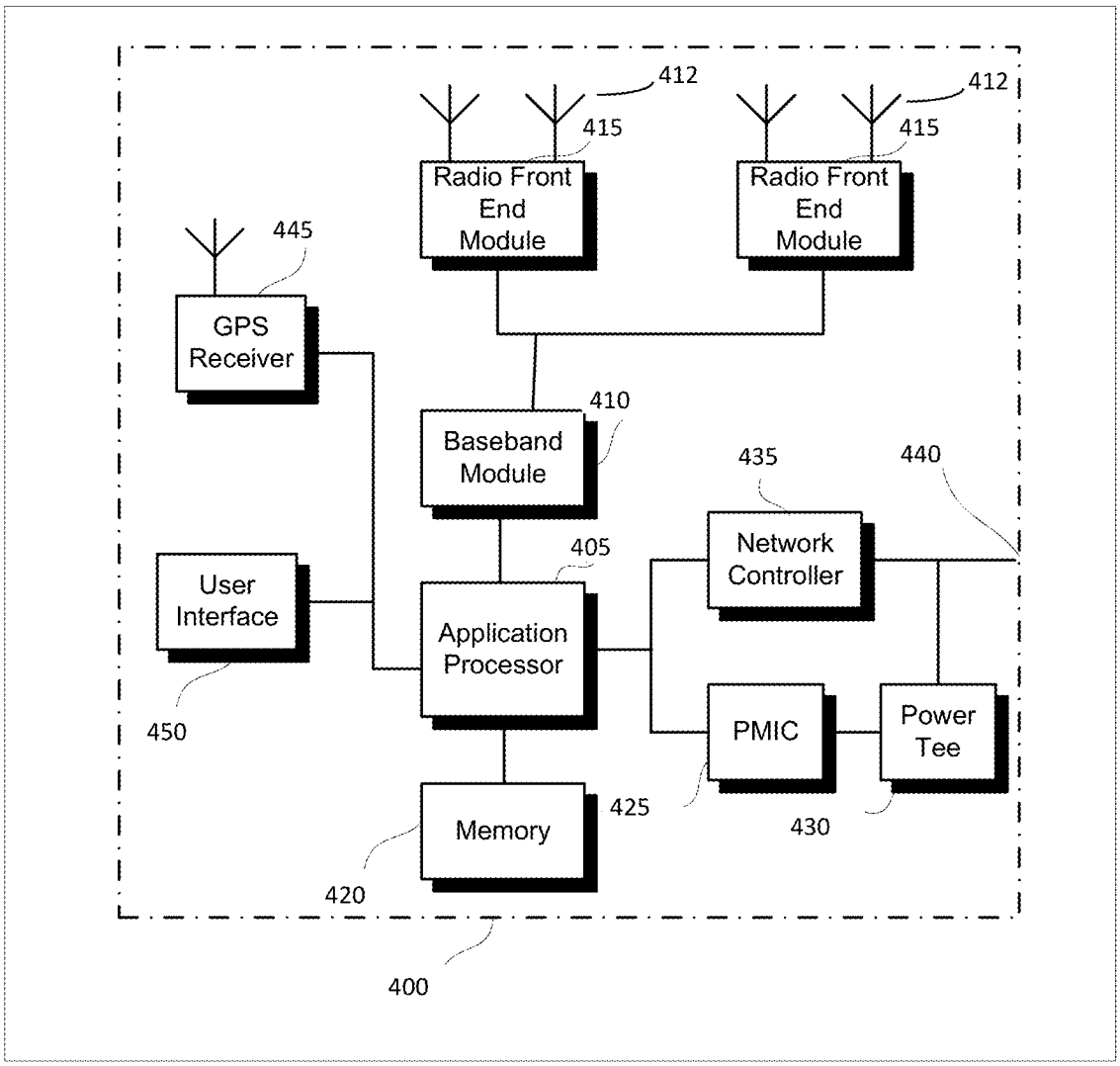

412
415
412
415
Radio Front End Module
Radio Front End Module
445
GPS Receiver
410
Baseband Module
435
440
Network Controller
405
User Interface
Application Processor
PMIC
Power Tee
450
425
430
Memory
420
400

FIG. 4

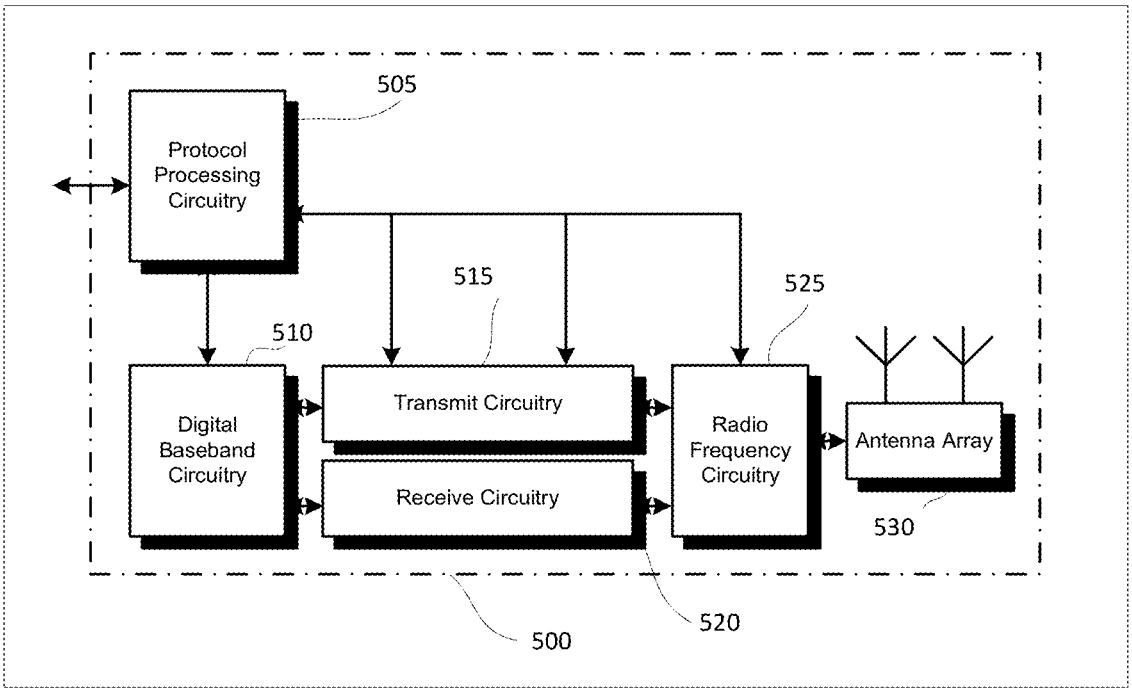

505
Protocol Processing Circuitry
515
525
510
Digital Baseband Circuitry
Transmit Circuitry
Receive Circuitry
Radio Frequency Circuitry
Antenna Array
530
500
520

FIG. 5

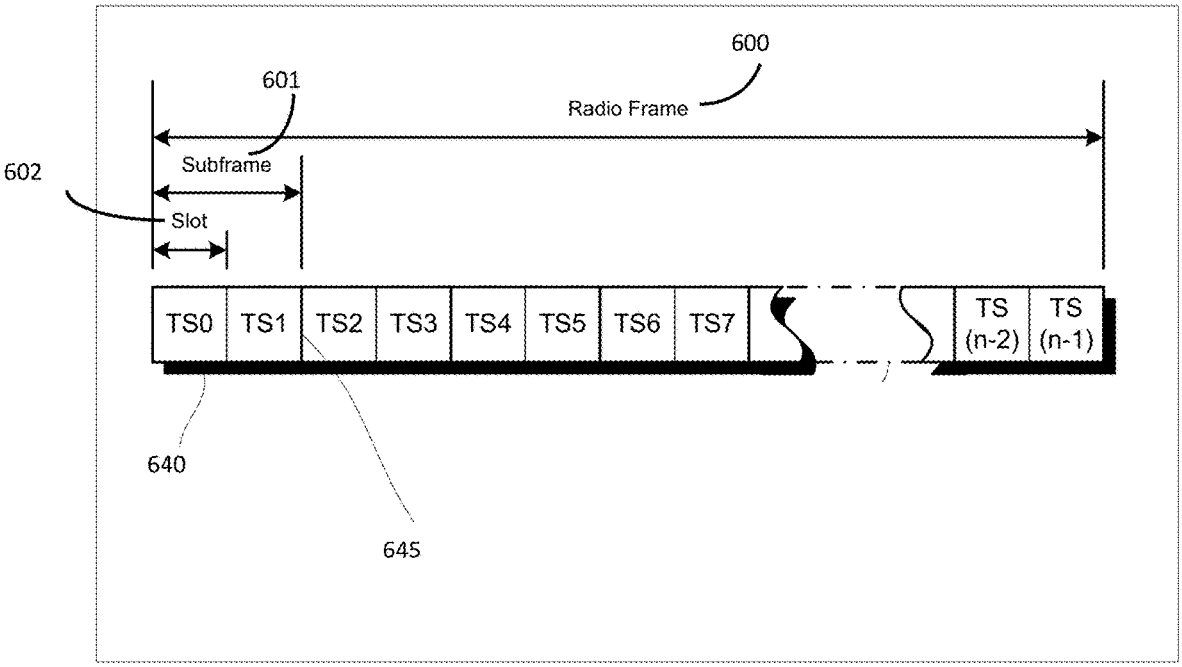

600
601
Radio Frame
Subframe
602
Slot
TS0
TS1
TS2
TS3
TS4
TS5
TS6
TS7
TS (n-2)
TS (n-1)
640
645

FIG. 6

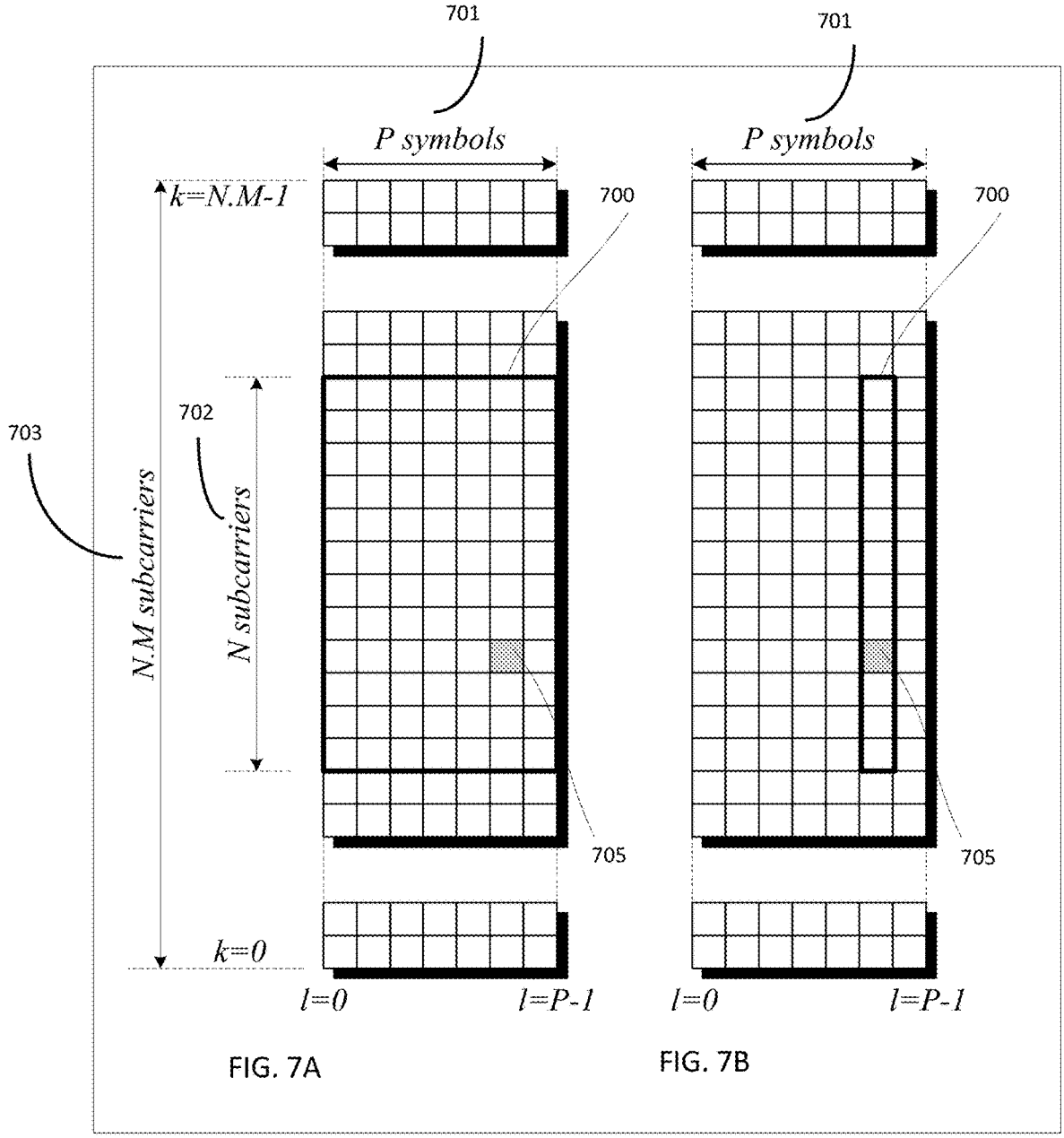

701
P symbols
k=N.M-1
700
703
702
N.M subcarriers
N subcarriers
705
k=0
l=0
l=P-1
701
P symbols
700
705
l=0
l=P-1

FIG. 7A

FIG. 7B

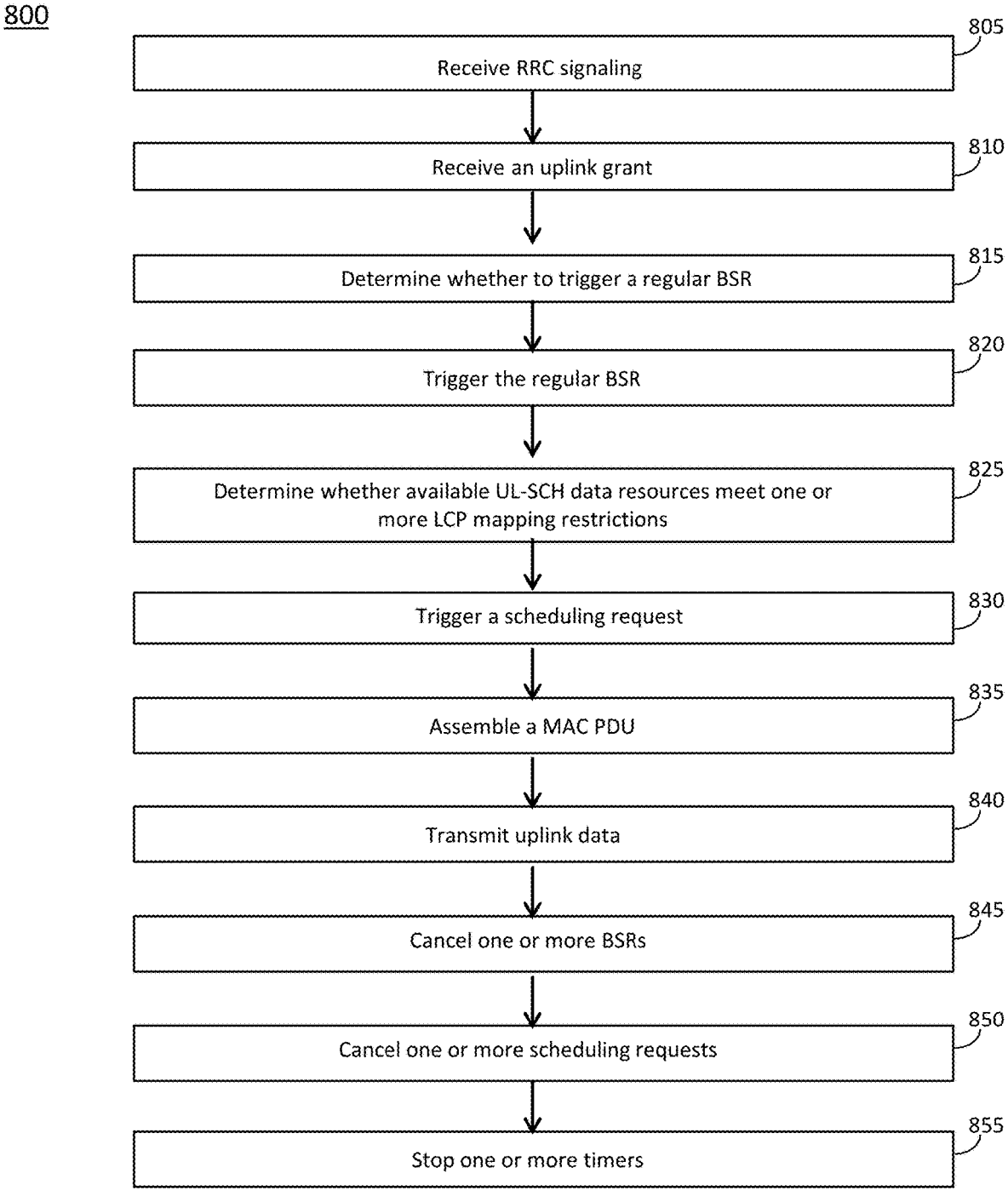

800
Receive RRC signaling
805
Receive an uplink grant
810
Determine whether to trigger a regular BSR
815
Trigger the regular BSR
820
Determine whether available UL-SCH data resources meet one or more LCP mapping restrictions
825
Trigger a scheduling request
830
Assemble a MAC PDU
835
Transmit uplink data
840
Cancel one or more BSRs
845
Cancel one or more scheduling requests
850
Stop one or more timers
855

FIG. 8

900

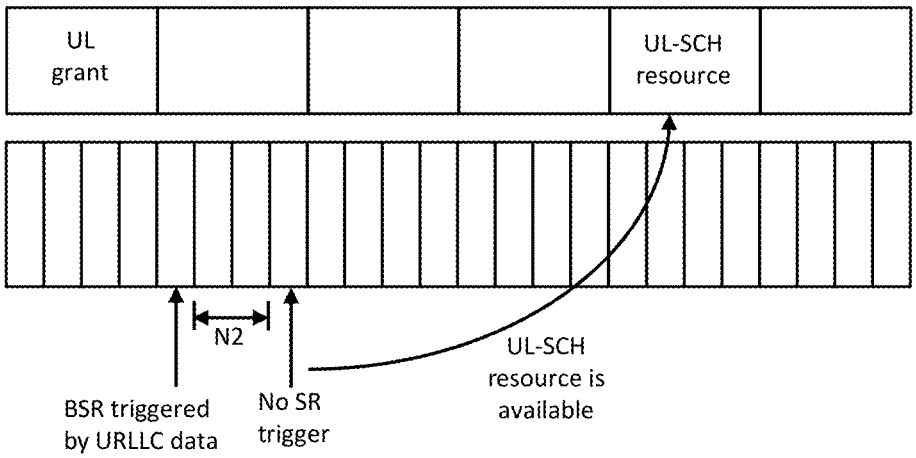

UL
grant
UL-SCH
resource
N2
BSR triggered
by URLLC data
No SR
trigger
UL-SCH
resource is
available

FIG. 9

1000

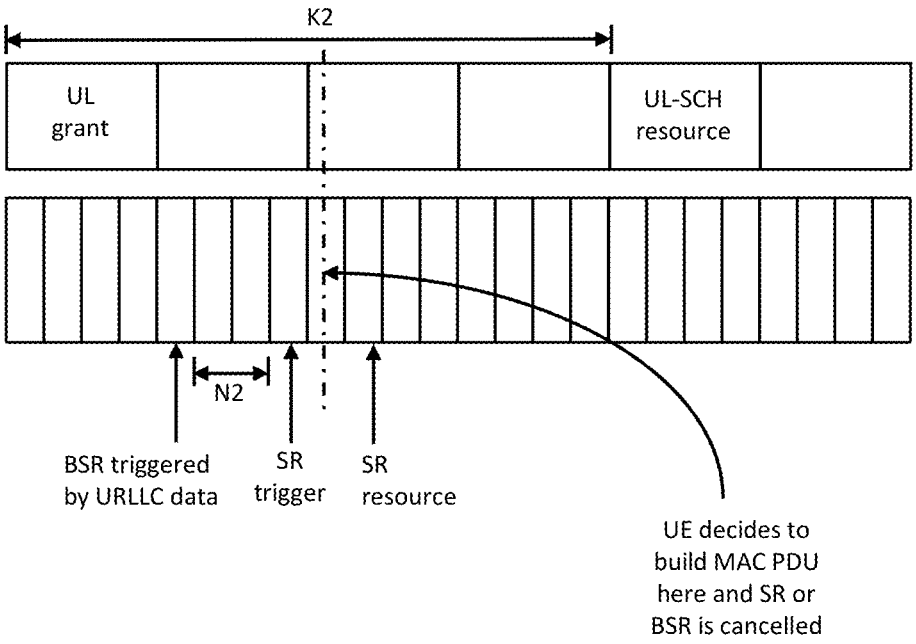

K2
UL grant
UL-SCH resource
N2
BSR triggered by URLLC data
SR trigger
SR resource
UE decides to build MAC PDU here and SR or BSR is cancelled

FIG. 10

1100

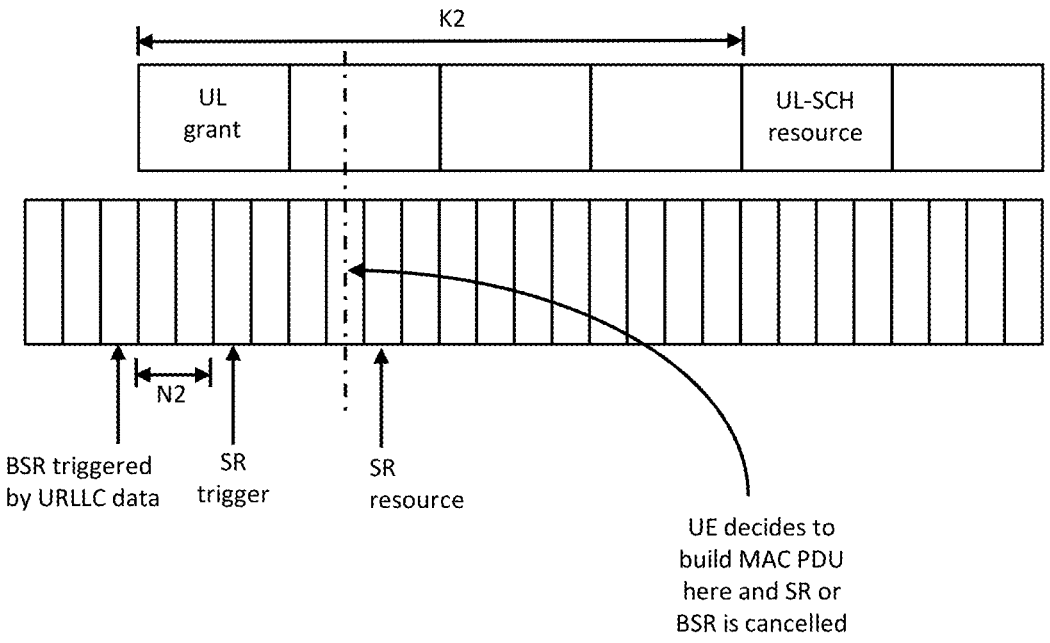

K2
UL grant
UL-SCH resource
N2
BSR triggered by URLLC data
SR trigger
SR resource
UE decides to build MAC PDU here and SR or BSR is cancelled

FIG. 11

1200

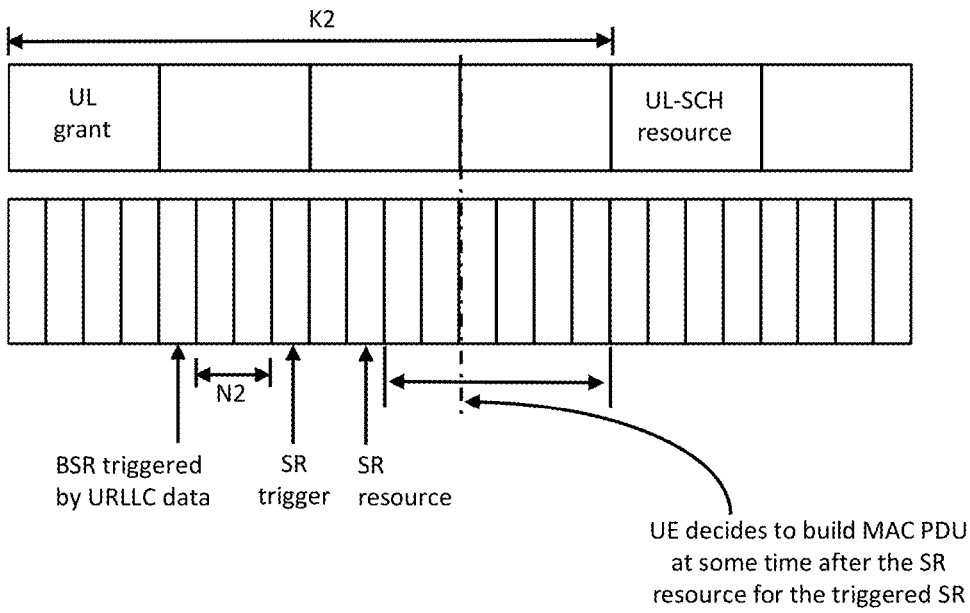

K2
UL grant
UL-SCH resource
N2
BSR triggered by URLLC data
SR trigger
SR resource
UE decides to build MAC PDU at some time after the SR resource for the triggered SR

FIG. 12

1300

```
-- ASN1START
-- TAG-LOGICAL-CHANNEL-CONFIG-START

LogicalChannelConfig ::=        SEQUENCE {
    ul-SpecificParameters           SEQUENCE {
        priority                        INTEGER (1..16),
        prioritisedBitRate              ENUMERATED {kBps0, kBps8, kBps16, kBps32, kBps64,
kBps128, kBps256, kBps512,
                                            kBps1024, kBps2048, kBps4096, kBps8192, kBps16384,
kBps32768, kBps65536, infinity},
        bucketSizeDuration              ENUMERATED {ms50, ms100, ms150, ms300, ms500, ms1000,
spare2, spare1},

        -- FFS: Detailed handling of restrictions (UP email discussion)
        -- Defined in L1 parameters but the value range must be checked.
        allowedSubCarrierSpacing        SubcarrierSpacing
                OPTIONAL,

        allowedTiming                   TYPE_FFS
                OPTIONAL,
        logicalChannelGroup             INTEGER (0..maxLCid)
                OPTIONAL,

        logicalChannelSR-Mask           BOOLEAN,

        logicalChannelSR-DelayTimerApplied  BOOLEAN
    }
                OPTIONAL,   -- Cond UL

    -- other parameters
        prioritizedSchedulingRequest      ENUMERATED {true}   OPTIONAL,   -- Need R
}

-- TAG-LOGICAL-CHANNEL-CONFIG-STOP
-- ASN1STOP
```

FIG. 13

# METHODS TO HANDLE SCHEDULING REQUESTS FOR ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC) IN NEW RADIO (NR) SYSTEMS

## PRIORITY CLAIM

This application claims priority under 35 USC **119**(*e*) to U.S. Provisional Patent Application Ser. No. 62/631,322, filed Feb. 15, 2018 [reference number AA8957-Z], which is incorporated by reference in its entirety.

## TECHNICAL FIELD

Embodiments pertain to wireless networks. Some embodiments relate to cellular communication networks including 3GPP (Third Generation Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, 3GPP LTE-A (LTE Advanced) networks, New Radio (NR) networks, and 5G networks, although the scope of the embodiments is not limited in this respect. Some embodiments relate to ultra-reliable low latency communication (URLLC) techniques.

## BACKGROUND

Base stations and mobile devices operating in a cellular network may exchange data. As demand for mobile services and high data rates increases, various challenges related to reliability and capacity may arise. In an example scenario, a large number of users may demand access to the network. In another example scenario, performance requirements may be more demanding for new systems and/or new applications in comparison to legacy systems and/or legacy applications. Examples of such performance requirements may include latency, reliability and/or others. Various techniques used in these and other scenarios may become challenging, including exchanging of control information and/or performance information between the base stations and mobile devices. Accordingly, there is a general need for methods to enable such techniques in these and other scenarios.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a functional diagram of an example network in accordance with some embodiments;

FIG. **1**B is a functional diagram of another example network in accordance with some embodiments;

FIG. **2** illustrates a block diagram of an example machine in accordance with some embodiments;

FIG. **3** illustrates a user device in accordance with some aspects;

FIG. **4** illustrates a base station in accordance with some aspects;

FIG. **5** illustrates an exemplary communication circuitry according to some aspects;

FIG. **6** illustrates an example of a radio frame structure in accordance with some embodiments;

FIG. **7**A and FIG. **7**B illustrate example frequency resources in accordance with some embodiments;

FIG. **8** illustrates the operation of a method of communication in accordance with some embodiments;

FIG. **9** illustrates example operations and elements in accordance with some embodiments;

FIG. **10** illustrates example operations and elements in accordance with some embodiments;



FIG. **11** illustrates example operations and elements in accordance with some embodiments;

FIG. **12** illustrates example operations and elements in accordance with some embodiments; and

FIG. **13** illustrates an example information element (IE) in accordance with some embodiments.

## DETAILED DESCRIPTION

The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

FIG. **1**A is a functional diagram of an example network in accordance with some embodiments. FIG. **1**B is a functional diagram of another example network in accordance with some embodiments. In references herein, "FIG. **1**" may include FIG. **1**A and FIG. **1**B. In some embodiments, the network **100** may be a Third Generation Partnership Project (3GPP) network. In some embodiments, the network **150** may be a 3GPP network. In a non-limiting example, the network **150** may be a new radio (NR) network. It should be noted that embodiments are not limited to usage of 3GPP networks, however, as other networks may be used in some embodiments. As an example, a Fifth Generation (5G) network may be used in some cases. As another example, a New Radio (NR) network may be used in some cases. As another example, a wireless local area network (WLAN) may be used in some cases. Embodiments are not limited to these example networks, however, as other networks may be used in some embodiments. In some embodiments, a network may include one or more components shown in FIG. **1**A. Some embodiments may not necessarily include all components shown in FIG. **1**A, and some embodiments may include additional components not shown in FIG. **1**A. In some embodiments, a network may include one or more components shown in FIG. **1**B. Some embodiments may not necessarily include all components shown in FIG. **1**B, and some embodiments may include additional components not shown in FIG. **1**B. In some embodiments, a network may include one or more components shown in FIG. **1**A and one or more components shown in FIG. **1**B. In some embodiments, a network may include one or more components shown in FIG. **1**A, one or more components shown in FIG. **1**B and one or more additional components.

The network **100** may comprise a radio access network (RAN) **101** and the core network **120** (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface **115**. For convenience and brevity sake, only a portion of the core network **120**, as well as the RAN **101**, is shown. In a non-limiting example, the RAN **101** may be an evolved universal terrestrial radio access network (E-UTRAN). In another non-limiting example, the RAN **101** may include one or more components of a New Radio (NR) network. In another non-limiting example, the RAN **101** may include one or more components of an E-UTRAN and one or more components of another network (including but not limited to an NR network).

The core network **120** may include a mobility management entity (MME) **122**, a serving gateway (serving GW) **124**, and packet data network gateway (PDN GW) **126**. In some embodiments, the network **100** may include (and/or support) one or more Evolved Node-B's (eNBs) **104** (which

may operate as base stations) for communicating with User Equipment (UE) **102**. The eNBs **104** may include macro eNBs and low power (LP) eNBs, in some embodiments.

In some embodiments, the network **100** may include (and/or support) one or more Next Generation Node-B's (gNBs) **105**. In some embodiments, one or more eNBs **104** may be configured to operate as gNBs **105**. Embodiments are not limited to the number of eNBs **104** shown in FIG. **1**A or to the number of gNBs **105** shown in FIG. **1**A. In some embodiments, the network **100** may not necessarily include eNBs **104**. Embodiments are also not limited to the connectivity of components shown in FIG. **1**A.

It should be noted that references herein to an eNB **104** or to a gNB **105** are not limiting. In some embodiments, one or more operations, methods and/or techniques (such as those described herein) may be practiced by a base station component (and/or other component), including but not limited to a gNB **105**, an eNB **104**, a serving cell, a transmit receive point (TRP) and/or other. In some embodiments, the base station component may be configured to operate in accordance with a New Radio (NR) protocol and/or NR standard, although the scope of embodiments is not limited in this respect. In some embodiments, the base station component may be configured to operate in accordance with a Fifth Generation (5G) protocol and/or 5G standard, although the scope of embodiments is not limited in this respect.

In some embodiments, one or more of the UEs **102**, gNBs **105**, and/or eNBs **104** may be configured to operate in accordance with an NR protocol and/or NR techniques. References to a UE **102**, eNB **104**, and/or gNB **105** as part of descriptions herein are not limiting. For instance, descriptions of one or more operations, techniques and/or methods practiced by a gNB **105** are not limiting. In some embodiments, one or more of those operations, techniques and/or methods may be practiced by an eNB **104** and/or other base station component.

In some embodiments, the UE **102** may transmit signals (data, control and/or other) to the gNB **105**, and may receive signals (data, control and/or other) from the gNB **105**. In some embodiments, the UE **102** may transmit signals (data, control and/or other) to the eNB **104**, and may receive signals (data, control and/or other) from the eNB **104**. These embodiments will be described in more detail below.

The MME **122** is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME **122** manages mobility aspects in access such as gateway selection and tracking area list management. The serving GW **124** terminates the interface toward the RAN **101**, and routes data packets between the RAN **101** and the core network **120**. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW **124** and the MME **122** may be implemented in one physical node or separate physical nodes. The PDN GW **126** terminates an SGi interface toward the packet data network (PDN). The PDN GW **126** routes data packets between the EPC **120** and the external PDN, and may be a key node for policy enforcement and charging data collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW **126** and the serving GW **124** may be implemented in one physical node or separated physical nodes.

In some embodiments, the eNBs **104** (macro and micro) terminate the air interface protocol and may be the first point of contact for a UE **102**. In some embodiments, an eNB **104** may fulfill various logical functions for the network **100**, including but not limited to RNC (radio network controller functions) such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

In some embodiments, UEs **102** may be configured to communicate Orthogonal Frequency Division Multiplexing (OFDM) communication signals with an eNB **104** and/or gNB **105** over a multicarrier communication channel in accordance with an Orthogonal Frequency Division Multiple Access (OFDMA) communication technique. In some embodiments, eNBs **104** and/or gNBs **105** may be configured to communicate OFDM communication signals with a UE **102** over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

The S1 interface **115** is the interface that separates the RAN **101** and the EPC **120**. It may be split into two parts: the S1-U, which carries traffic data between the eNBs **104** and the serving GW **124**, and the S1-MME, which is a signaling interface between the eNBs **104** and the MME **122**. The X2 interface is the interface between eNBs **104**. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNBs **104**, while the X2-U is the user plane interface between the eNBs **104**.

In some embodiments, similar functionality and/or connectivity described for the eNB **104** may be used for the gNB **105**, although the scope of embodiments is not limited in this respect. In a non-limiting example, the S1 interface **115** (and/or similar interface) may be split into two parts: the S1-U, which carries traffic data between the gNBs **105** and the serving GW **124**, and the S1-MME, which is a signaling interface between the gNBs **104** and the MME **122**. The X2 interface (and/or similar interface) may enable communication between eNBs **104**, communication between gNBs **105** and/or communication between an eNB **104** and a gNB **105**.

With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW **126**. Similarly, a picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise

femtocell. In some embodiments, various types of gNBs **105** may be used, including but not limited to one or more of the eNB types described above.

In some embodiments, the network **150** may include one or more components configured to operate in accordance with one or more 3GPP standards, including but not limited to an NR standard. The network **150** shown in FIG. **1**B may include a next generation RAN (NG-RAN) **155**, which may include one or more gNBs **105**. In some embodiments, the network **150** may include the E-UTRAN **160**, which may include one or more eNBs. The E-UTRAN **160** may be similar to the RAN **101** described herein, although the scope of embodiments is not limited in this respect.

In some embodiments, the network **150** may include the MME **165**. The MME **165** may be similar to the MME **122** described herein, although the scope of embodiments is not limited in this respect. The MME **165** may perform one or more operations or functionality similar to those described herein regarding the MME **122**, although the scope of embodiments is not limited in this respect.

In some embodiments, the network **150** may include the SGW **170**. The SGW **170** may be similar to the SGW **124** described herein, although the scope of embodiments is not limited in this respect. The SGW **170** may perform one or more operations or functionality similar to those described herein regarding the SGW **124**, although the scope of embodiments is not limited in this respect.

In some embodiments, the network **150** may include component(s) and/or module(s) for functionality for a user plane function (UPF) and user plane functionality for PGW (PGW-U), as indicated by **175**. In some embodiments, the network **150** may include component(s) and/or module(s) for functionality for a session management function (SMF) and control plane functionality for PGW (PGW-C), as indicated by **180**. In some embodiments, the component(s) and/or module(s) indicated by **175** and/or **180** may be similar to the PGW **126** described herein, although the scope of embodiments is not limited in this respect. The component(s) and/or module(s) indicated by **175** and/or **180** may perform one or more operations or functionality similar to those described herein regarding the PGW **126**, although the scope of embodiments is not limited in this respect. One or both of the components **170**, **172** may perform at least a portion of the functionality described herein for the PGW **126**, although the scope of embodiments is not limited in this respect.

Embodiments are not limited to the number or type of components shown in FIG. **1**B. Embodiments are also not limited to the connectivity of components shown in FIG. **1**B.

In some embodiments, a downlink resource grid may be used for downlink transmissions from an eNB **104** to a UE **102**, while uplink transmission from the UE **102** to the eNB **104** may utilize similar techniques. In some embodiments, a downlink resource grid may be used for downlink transmissions from a gNB **105** to a UE **102**, while uplink transmission from the UE **102** to the gNB **105** may utilize similar techniques. The grid may be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid correspond to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element (RE). There are several different physical downlink channels that are conveyed using such resource blocks. With particular relevance to this disclosure, two of these physical downlink channels are the physical downlink shared channel and the physical down link control channel.

As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software.

FIG. **2** illustrates a block diagram of an example machine in accordance with some embodiments. The machine **200** is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine **200** may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine **200** may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine **200** may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine **200** may be a UE **102**, eNB **104**, gNB **105**, access point (AP), station (STA), user, device, mobile device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

Examples as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

Accordingly, the term "module" is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part

or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

The machine (e.g., computer system) **200** may include a hardware processor **202** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory **204** and a static memory **206**, some or all of which may communicate with each other via an interlink (e.g., bus) **208**. The machine **200** may further include a display unit **210**, an alphanumeric input device **212** (e.g., a keyboard), and a user interface (UI) navigation device **214** (e.g., a mouse). In an example, the display unit **210**, input device **212** and UI navigation device **214** may be a touch screen display. The machine **200** may additionally include a storage device (e.g., drive unit) **216**, a signal generation device **218** (e.g., a speaker), a network interface device **220**, and one or more sensors **221**, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine **200** may include an output controller **228**, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

The storage device **216** may include a machine readable medium **222** on which is stored one or more sets of data structures or instructions **224** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **224** may also reside, completely or at least partially, within the main memory **204**, within static memory **206**, or within the hardware processor **202** during execution thereof by the machine **200**. In an example, one or any combination of the hardware processor **202**, the main memory **204**, the static memory **206**, or the storage device **216** may constitute machine readable media. In some embodiments, the machine readable medium may be or may include a non-transitory computer-readable storage medium. In some embodiments, the machine readable medium may be or may include a computer-readable storage medium.

While the machine readable medium **222** is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions **224**. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine **200** and that cause the machine **200** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

The instructions **224** may further be transmitted or received over a communications network **226** using a transmission medium via the network interface device **220** utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device **220** may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network **226**. In an example, the network interface device **220** may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device **220** may wirelessly communicate using Multiple User MIMO techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine **200**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

FIG. **3** illustrates a user device in accordance with some aspects. In some embodiments, the user device **300** may be a mobile device. In some embodiments, the user device **300** may be or may be configured to operate as a User Equipment (UE). In some embodiments, the user device **300** may be arranged to operate in accordance with a new radio (NR) protocol. In some embodiments, the user device **300** may be arranged to operate in accordance with a Third Generation Partnership Protocol (3GPP) protocol. The user device **300** may be suitable for use as a UE **102** as depicted in FIG. **1**, in some embodiments. It should be noted that in some embodiments, a UE, an apparatus of a UE, a user device or an apparatus of a user device may include one or more of the components shown in one or more of FIGS. **2**, **3**, and **5**. In some embodiments, such a UE, user device and/or apparatus may include one or more additional components.

In some aspects, the user device **300** may include an application processor **305**, baseband processor **310** (also referred to as a baseband module), radio front end module (RFEM) **315**, memory **320**, connectivity module **325**, near field communication (NFC) controller **330**, audio driver **335**, camera driver **340**, touch screen **345**, display driver **350**, sensors **355**, removable memory **360**, power management integrated circuit (PMIC) **365** and smart battery **370**. In some aspects, the user device **300** may be a User Equipment (UE).

In some aspects, application processor **305** may include, for example, one or more CPU cores and one or more of cache memory, low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as serial peripheral interface (SPI), inter-integrated circuit ($I^2C$) or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input-output (IO), memory card controllers such as secure digital/multi-media card (SD/MMC) or similar, universal serial bus (USB) interfaces, mobile industry processor interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports.

In some aspects, baseband module **310** may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board, and/or a multi-chip module containing two or more integrated circuits.

FIG. **4** illustrates a base station in accordance with some aspects. In some embodiments, the base station **400** may be or may be configured to operate as an Evolved Node-B (eNB). In some embodiments, the base station **400** may be or may be configured to operate as a Next Generation Node-B (gNB). In some embodiments, the base station **400** may be arranged to operate in accordance with a new radio (NR) protocol. In some embodiments, the base station **400** may be arranged to operate in accordance with a Third Generation Partnership Protocol (3GPP) protocol. It should be noted that in some embodiments, the base station **400** may be a stationary non-mobile device. The base station **400** may be suitable for use as an eNB **104** as depicted in FIG. **1**, in some embodiments. The base station **400** may be suitable for use as a gNB **105** as depicted in FIG. **1**, in some embodiments. It should be noted that in some embodiments, an eNB, an apparatus of an eNB, a gNB, an apparatus of a gNB, a base station and/or an apparatus of a base station may include one or more of the components shown in one or more of FIGS. **2**, **4**, and **5**. In some embodiments, such an eNB, gNB, base station and/or apparatus may include one or more additional components.

FIG. **4** illustrates a base station or infrastructure equipment radio head **400** in accordance with some aspects. The base station **400** may include one or more of application processor **405**, baseband modules **410**, one or more radio front end modules **415**, memory **420**, power management circuitry **425**, power tee circuitry **430**, network controller **435**, network interface connector **440**, satellite navigation receiver module **445**, and user interface **450**. In some aspects, the base station **400** may be an Evolved Node-B (eNB), which may be arranged to operate in accordance with a 3GPP protocol, new radio (NR) protocol and/or Fifth Generation (5G) protocol. In some aspects, the base station **400** may be a Next Generation Node-B (gNB), which may be arranged to operate in accordance with a 3GPP protocol, new radio (NR) protocol and/or Fifth Generation (5G) protocol.

In some aspects, application processor **405** may include one or more CPU cores and one or more of cache memory, low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, $I^2C$ or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose TO, memory card controllers such as SD/MMC or similar, USB interfaces, MIPI interfaces and Joint Test Access Group (JTAG) test access ports.

In some aspects, baseband processor **410** may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits.

In some aspects, memory **420** may include one or more of volatile memory including dynamic random access memory (DRAM) and/or synchronous dynamic random access memory (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM), magneto-resistive random access memory (MRAM) and/or a three-dimensional cross-point memory. Memory **420** may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

In some aspects, power management integrated circuitry **425** may include one or more of voltage regulators, surge protectors, power alarm detection circuitry and one or more backup power sources such as a battery or capacitor. Power alarm detection circuitry may detect one or more of brown out (under-voltage) and surge (over-voltage) conditions.

In some aspects, power tee circuitry **430** may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the base station **400** using a single cable. In some aspects, network controller **435** may provide connectivity to a network using a standard network interface protocol such as Ethernet. Network connectivity may be provided using a physical connection which is one of electrical (commonly referred to as copper interconnect), optical or wireless.

In some aspects, satellite navigation receiver module **445** may include circuitry to receive and decode signals transmitted by one or more navigation satellite constellations such as the global positioning system (GPS), Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS), Galileo and/or BeiDou. The receiver **445** may provide data to application processor **405** which may include one or more of position data or time data. Application processor **405** may use time data to synchronize operations with other radio base stations. In some aspects, user interface **450** may include one or more of physical or virtual buttons, such as a reset button, one or more indicators such as light emitting diodes (LEDs) and a display screen.

FIG. **5** illustrates an exemplary communication circuitry according to some aspects. Circuitry **500** is alternatively grouped according to functions. Components as shown in **500** are shown here for illustrative purposes and may include other components not shown here in FIG. **5**. In some aspects, the communication circuitry **500** may be used for millimeter wave communication, although aspects are not limited to millimeter wave communication. Communication at any suitable frequency may be performed by the communication circuitry **500** in some aspects.

It should be noted that a device, such as a UE **102**, eNB **104**, gNB **105**, the user device **300**, the base station **400**, the machine **200** and/or other device may include one or more components of the communication circuitry **500**, in some aspects.

The communication circuitry **500** may include protocol processing circuitry **505**, which may implement one or more of medium access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), radio resource control (RRC) and non-access stratum (NAS) functions. Protocol processing circuitry **505** may include one or more processing cores (not shown) to execute instructions and one or more memory structures (not shown) to store program and data information.

The communication circuitry **500** may further include digital baseband circuitry **510**, which may implement physi-

cal layer (PHY) functions including one or more of hybrid automatic repeat request (HARQ) functions, scrambling and/or descrambling, coding and/or decoding, layer mapping and/or de-mapping, modulation symbol mapping, received symbol and/or bit metric determination, multi-antenna port pre-coding and/or decoding which may include one or more of space-time, space-frequency or spatial coding, reference signal generation and/or detection, preamble sequence generation and/or decoding, synchronization sequence generation and/or detection, control channel signal blind decoding, and other related functions.

The communication circuitry **500** may further include transmit circuitry **515**, receive circuitry **520** and/or antenna array circuitry **530**. The communication circuitry **500** may further include radio frequency (RF) circuitry **525**. In an aspect of the disclosure, RF circuitry **525** may include multiple parallel RF chains for one or more of transmit or receive functions, each connected to one or more antennas of the antenna array **530**.

In an aspect of the disclosure, protocol processing circuitry **505** may include one or more instances of control circuitry (not shown) to provide control functions for one or more of digital baseband circuitry **510**, transmit circuitry **515**, receive circuitry **520**, and/or radio frequency circuitry **525**.

In some embodiments, processing circuitry may perform one or more operations described herein and/or other operation(s). In a non-limiting example, the processing circuitry may include one or more components such as the processor **202**, application processor **305**, baseband module **310**, application processor **405**, baseband module **410**, protocol processing circuitry **505**, digital baseband circuitry **510**, similar component(s) and/or other component(s).

In some embodiments, a transceiver may transmit one or more elements (including but not limited to those described herein) and/or receive one or more elements (including but not limited to those described herein). In a non-limiting example, the transceiver may include one or more components such as the radio front end module **315**, radio front end module **415**, transmit circuitry **515**, receive circuitry **520**, radio frequency circuitry **525**, similar component(s) and/or other component(s).

One or more antennas (such as **230**, **312**, **412**, **530** and/or others) may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, one or more of the antennas (such as **230**, **312**, **412**, **530** and/or others) may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

In some embodiments, the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may be a mobile device and/or portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may be configured to operate in accordance with 3GPP standards, although the scope of the embodiments is not limited in this respect. In some embodiments, the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may be configured to operate in accordance with new radio (NR) standards, although the scope of the embodiments is not limited in this respect. In some embodiments, the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

Although the UE **102**, eNB **104**, gNB **105**, user device **300**, base station **400**, machine **200** and/or other device described herein may each be illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

It should be noted that in some embodiments, an apparatus of the UE **102**, eNB **104**, gNB **105**, machine **200**, user device **300** and/or base station **400** may include various components shown in FIGS. **2-5**. Accordingly, techniques and operations described herein that refer to the UE **102** may be applicable to an apparatus of a UE. In addition, techniques and operations described herein that refer to the eNB **104** may be applicable to an apparatus of an eNB. In addition, techniques and operations described herein that refer to the gNB **105** may be applicable to an apparatus of a gNB.

FIG. **6** illustrates an example of a radio frame structure in accordance with some embodiments. FIGS. **7**A and **7**B illustrate example frequency resources in accordance with some embodiments. In references herein, "FIG. **7**" may include FIG. **7**A and FIG. **7**B. It should be noted that the examples shown in FIGS. **6-7** may illustrate some or all of the concepts and techniques described herein in some cases,

but embodiments are not limited by the examples. For instance, embodiments are not limited by the name, number, type, size, ordering, arrangement and/or other aspects of the time resources, symbol periods, frequency resources, PRBs and other elements as shown in FIGS. **6-7**. Although some of the elements shown in the examples of FIGS. **6-7** may be included in a 3GPP LTE standard, 5G standard, NR standard and/or other standard, embodiments are not limited to usage of such elements that are included in standards.

An example of a radio frame structure that may be used in some aspects is shown in FIG. **6**. In this example, radio frame **600** has a duration of 10 ms. Radio frame **600** is divided into slots **602** each of duration 0.5 ms, and numbered from 0 to 19. Additionally, each pair of adjacent slots **602** numbered 2i and 2i+1, where i is an integer, is referred to as a subframe **601**.

In some aspects using the radio frame format of FIG. **6**, each subframe **601** may include a combination of one or more of downlink control information, downlink data information, uplink control information and uplink data information. The combination of information types and direction may be selected independently for each subframe **602**.

Referring to FIGS. **7**A and **7**B, in some aspects, a subcomponent of a transmitted signal consisting of one subcarrier in the frequency domain and one symbol interval in the time domain may be termed a resource element. Resource elements may be depicted in a grid form as shown in FIG. **7**A and FIG. **7**B.

In some aspects, illustrated in FIG. **7**A, resource elements may be grouped into rectangular resource blocks **700** consisting of 12 subcarriers in the frequency domain and the P symbols in the time domain, where P may correspond to the number of symbols contained in one slot, and may be 6, 7, or any other suitable number of symbols.

In some alternative aspects, illustrated in FIG. **7**B, resource elements may be grouped into resource blocks **700** consisting of 12 subcarriers (as indicated by **702**) in the frequency domain and one symbol in the time domain. In the depictions of FIG. **7**A and FIG. **7**B, each resource element **705** may be indexed as (k, 1) where k is the index number of subcarrier, in the range 0 to N·M−1 (as indicated by **703**), where N is the number of subcarriers in a resource block, and M is the number of resource blocks spanning a component carrier in the frequency domain.

In accordance with some embodiments, an apparatus of a UE **102** may comprise memory. The apparatus may further comprise processing circuitry. The processing circuitry may supports a medium access control (MAC) entity. The processing circuitry may be configured to decode radio resource control (RRC) signaling from a gNB **105**. The RRC signaling may allocate one or more logical channels to one or more logical channel groups (LCG) for uplink transmissions. The processing circuitry may be further configured to decode an uplink grant for uplink shared channel (UL-SCH) data transmission by the UE **102**. The processing circuitry may be further configured to, if uplink data for one of the logical channels becomes available to the MAC entity, determine whether to trigger a regular buffer status report (BSR) to provide the gNB **105** with information about uplink data volumes in the MAC entity, based at least partly on: a priority of the logical channel of the uplink data; and for the LCG to which the logical channel of the uplink data belongs, uplink data volumes of the logical channels of the LCG. The processing circuitry may be further configured to, if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available UL-SCH data resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel of the uplink data: trigger a scheduling request to request UL-SCH data resources for a new transmission of the uplink data. These embodiments are described in more detail below.

FIG. **8** illustrates the operation of a method of communication in accordance with some embodiments. It is important to note that embodiments of the method **800** may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. **8**. In addition, embodiments of the method **800** are not necessarily limited to the chronological order that is shown in FIG. **8**. In describing the method **800**, reference may be made to one or more figures, although it is understood that the method **800** may be practiced with any other suitable systems, interfaces and components.

In some embodiments, a UE **102** may perform one or more operations of the method **800**, but embodiments are not limited to performance of the method **800** and/or operations of it by the UE **102**. In some embodiments, another device and/or component (including but not limited to the gNB **105**) may perform one or more operations of the method **800**. In some embodiments, another device and/or component (including but not limited to the gNB **105**) may perform one or more operations that may be similar to one or more operations of the method **800**. In some embodiments, another device and/or component (including but not limited to the gNB **105**) may perform one or more operations that may be reciprocal to one or more operations of the method **800**. In a non-limiting example, the gNB **105** may perform an operation that may be the same as, similar to, reciprocal to and/or related to an operation of the method **800**, in some embodiments.

It should be noted that one or more operations of the method **800** (and/or other method) may be the same as, similar to and/or reciprocal to one or more operations of another method. In a non-limiting example, an operation of the method **800** may include reception of an element (such as a frame, block, message and/or other) by the UE **102**, and an operation of another method may include transmission of a same element (and/or similar element) by the gNB **105**. In some cases, descriptions of operations and techniques of one method (such as **800** and/or others) may be relevant to other methods (such as **800** and/or others). Such technique and concepts may be related to RRC signaling, BSRs, scheduling requests, logical channels, LCP prioritization, triggering of BSR(s), triggering of scheduling request(s), cancellation of BSR(s), cancellation of scheduling request(s) and/or other techniques/concepts.

The method **800** and other methods described herein may refer to eNBs **104**, gNBs **105** and/or UEs **102** operating in accordance with 3GPP standards, 5G standards, NR standards and/or other standards. However, embodiments are not limited to performance of those methods by those components, and may also be performed by other devices, such as a Wi-Fi access point (AP) or user station (STA). In addition, the method **800** and other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including systems configured to operate according to various IEEE standards such as IEEE 802.11. The method **800** may also be applicable to an apparatus of a UE **102**, an apparatus of an eNB **104**, an apparatus of a gNB **105** and/or an apparatus of another device described above.

It should also be noted that embodiments are not limited by references herein (such as in descriptions of the method **800** and/or other descriptions herein) to transmission, recep-

tion and/or exchanging of elements such as frames, messages, requests, indicators, signals or other elements. In some embodiments, such an element may be generated, encoded or otherwise processed by processing circuitry (such as by a baseband processor included in the processing circuitry) for transmission. The transmission may be performed by a transceiver or other component, in some cases. In some embodiments, such an element may be decoded, detected or otherwise processed by the processing circuitry (such as by the baseband processor). The element may be received by a transceiver or other component, in some cases. In some embodiments, the processing circuitry and the transceiver may be included in a same apparatus. The scope of embodiments is not limited in this respect, however, as the transceiver may be separate from the apparatus that comprises the processing circuitry, in some embodiments.

One or more of the elements (such as messages, parameters, operations and/or other) described herein may be included in a standard and/or protocol, including but not limited to Third Generation Partnership Project (3GPP), 3GPP Long Term Evolution (LTE), Fourth Generation (4G), Fifth Generation (5G), New Radio (NR) and/or other. Embodiments are not limited to those particular elements, as similar element(s) and/or alternate element(s) may be used, in some embodiments. The scope of embodiments is also not limited to usage of elements that are included in standards.

In some embodiments, the UE **102** may be arranged to operate in accordance with a new radio (NR) protocol. In some embodiments, the gNB **105** may be arranged to operate in accordance with an NR protocol.

In some embodiments, the UE **102** may support a medium access control (MAC) entity. In some embodiments, the UE **102** may comprise processing circuitry, and the processing circuitry may support the MAC entity. In some embodiments, the processing circuitry may: support the MAC entity; support one or more additional entities; perform additional functionality other than functionality of the MAC entity; and/or other.

At operation **805**, the UE **102** may receive radio resource control (RRC) signaling. Embodiments are not limited to usage of RRC signaling in this operation or in other operations described herein, as other types of control signaling may be used in some embodiments.

In some embodiments, the UE **102** may receive the RRC signaling from the gNB **105**, although the scope of embodiments is not limited in this respect. In some embodiments, the RRC signaling may allocate one or more logical channels to one or more logical channel groups (LCG) for uplink transmissions. In some embodiments, the RRC signaling may include information related to allocation of one or more logical channels to one or more LCGs for uplink transmissions.

In some embodiments, the RRC signaling may include information related to logical channel prioritization (LCP) mapping restrictions. Non-limiting examples of such information include, but are not limited to: one or more allowed-SCSlist parameters, one or more maxPUSCH-duration parameters, one or more configuredGrantType1Allowed parameters, and one or more allowedServingCells parameters. In some embodiments, the RRC signaling may include, for each logical channel: an allowed-SCSlist parameter, a maxPUSCH-duration parameter, a configuredGrantType1Allowed parameter, and an allowed-ServingCells parameter.

In some embodiments, the allowed-SCSlist parameter may set allowed subcarrier spacing(s) for transmission, although the scope of embodiments is not limited in this respect. In some embodiments, the maxPUSCH-duration parameter may set a maximum PUSCH duration for transmission, although the scope of embodiments is not limited in this respect.

In some embodiments, the RRC signaling may include multiple RRC messages, although the scope of embodiments is not limited in this respect. In some embodiments, multiple RRC messages may be used to communicate multiple elements. In a non-limiting example, a first RRC message may include information related to the allocation of the logical channels into LCGs, and a second RRC message may include information related to LCP mapping restrictions. The scope of embodiments is not limited to usage of multiple RRC messages to communicate multiple elements, however. An RRC message may include multiple elements, in some embodiments. For instance, one RRC message may include information related to the allocation of the logical channels into LCGs, and may also include information related to the LCP mapping restrictions, in some embodiments.

At operation **810**, the UE **102** may receive an uplink grant. In some embodiments, the UE **102** may receive the uplink grant from the gNB **105**, although the scope of embodiments is not limited in this respect. In some embodiments, the uplink grant may be for uplink data transmission and/or uplink shared channel (UL-SCH) data transmission by the UE **102**. In some embodiments, the uplink grant may include information related to resources to be used for uplink data transmission and/or UL-SCH data transmission by the UE **102**.

At operation **815**, the UE **102** may determine whether to trigger a regular BSR. In some embodiments, the UE **102** may determine whether to trigger a BSR, including but not limited to a regular BSR. At operation **820**, the UE **102** may trigger the regular BSR. In some embodiments, the UE **102** may trigger the regular BSR if it is determined that the UE is to trigger the BSR. In some embodiments, the UE **102** may trigger a BSR, including but not limited to a regular BSR.

In some embodiments, the BSR and/or regular BSR may be used to provide the gNB **105** with information about uplink data volumes in the MAC entity, although the scope of embodiments is not limited in this respect.

In some embodiments, the UE **102** may determine whether to trigger the regular BSR (and/or BSR) if uplink data for one of the logical channels becomes available to the MAC entity of the UE **102**, although the scope of embodiments is not limited in this respect.

In some embodiments, uplink data for one of the logical channels may become available to the MAC entity of the UE **102**. The UE **102** may determine whether to trigger the regular BSR (and/or BSR) based at least partly on one or more of: a priority of the logical channel of the uplink data; for the LCG to which the logical channel of the uplink data belongs: uplink data volumes of the logical channels of the LCG; and/or other.

In some embodiments, the UE **102** may determine to trigger the regular BSR (and/or BSR) if: the priority of the logical channel of the uplink data is higher than priorities of any logical channel containing available uplink data, for the logical channels of any of the LCGs; or for the logical channels of the LCG to which the logical channel of the uplink data belongs, none of the logical channels contains available uplink data.

In some embodiments, the UE **102** may, if uplink data for a logical channel becomes available to the MAC entity, determine whether to trigger the regular BSR (and/or BSR)

based at least partly on whether a priority of the logical channel of the uplink data is higher than priorities of other logical channels.

In some embodiments, the UE **102** may, if uplink data for one of the logical channels becomes available to the MAC entity, determine whether to trigger the regular BSR (and/or BSR) based at least partly on the logical channel for the uplink data.

At operation **825**, the UE **102** may determine whether available UL-SCH data resources meet one or more logical LCP mapping restrictions. At operation **830**, the UE **102** may trigger a scheduling request. In some embodiments, the UE **102** may trigger the scheduling request to request UL-SCH data resources for a new transmission of the uplink data, although the scope of embodiments is not limited in this respect.

In some embodiments, the UE **102** may trigger the scheduling request if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available UL-SCH data resources do not meet one or more LCP mapping restrictions configured for the logical channel of the uplink data. In some embodiments, one or more additional conditions may be used to determine whether to trigger the scheduling request.

In some embodiments, may, if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, trigger the scheduling request if: there are no UL-SCH data resources available for the new transmission; or if the MAC entity is configured with one or more configured uplink grants and a logicalChannelSR-Mask of the logical channel that triggered the regular BSR is set to false; or if UL-SCH data resources available for the new transmission do not meet one or more LCP mapping restrictions configured for the logical channel that triggered the BSR (and/or regular BSR).

In some embodiments, the UE **102** may trigger the scheduling request if the logical channel of the uplink data is not allowed to use the available UL-SCH data resources because the logical channel of the uplink data does not meet criteria related to: an allowed subcarrier spacing of the available UL-SCH data resources; a maximum PUSCH duration of the available UL-SCH data resource; and/or other.

In some embodiments, the UE **102** may determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions if: a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes a subcarrier spacing index associated to the uplink grant; and a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant. In some embodiments, the RRC signaling may include the allowed-SCSlist and/or the maxPUSCH-duration, although the scope of embodiments is not limited in this respect.

In some embodiments, the UE **102** may determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions if: a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes a subcarrier spacing index associated to the uplink grant; a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant; a configuredGrantType1Allowed for the logical channel of the uplink data is set to true in case the uplink grant is a configured grant Type 1; and allowedServingCells for the logical channel of the uplink data includes cell information associated to the uplink grant. In some embodiments, the RRC signaling may include the allowed-SCSlist, the maxPUSCH-duration, the configuredGrantType1Allowed and/or the allowedServingCells, although the scope of embodiments is not limited in this respect.

At operation **835**, the UE **102** may assemble a MAC protocol data unit (PDU). At operation **840**, the UE **102** may transmit uplink data. At operation **845**, the UE **102** may cancel one or more BSRs. At operation **850**, the UE **102** may cancel one or more scheduling requests. At operation **855**, the UE **102** may stop one or more timers.

In some cases, one or more of operations **835-855** may be performed. Non-limiting examples are given below.

In some embodiments, the UE **102** may: assemble a MAC PDU for transmission; cancel all current pending SRs; and stop each respective sr-ProhibitTimer for the pending SRs at a later time when the MAC PDU is transmitted.

In some embodiments, the UE **102** may: assemble a MAC PDU for transmission; and cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

In some embodiments, the UE **102** may: refrain from cancellation of the regular BSR or the triggered SR even if the UE **102** builds a MAC PDU including the regular BSR, provided that the logical channel of the uplink data is not allowed to use available UL-SCH resources for transmission of the MAC PDU.

In some embodiments, the UE **102** may: assemble a MAC PDU that includes the regular BSR; and cancel the regular BSR or the triggered SR at a later time when the UE **102** transmits the MAC PDU that includes the regular BSR.

In some embodiments, the UE **102** may: assemble a MAC PDU that includes the regular BSR; and cancel all current pending SRs and BSRs at a later time when the UE **102** transmits the MAC PDU that includes the regular BSR.

In some embodiments, the UE **102** may: assemble a MAC PDU for transmission; cancel all pending SRs triggered prior to assembly of the MAC PDU; stop each respective sr-ProhibitTimer for the pending SRs when the MAC PDU is transmitted; and cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

In some embodiments, the uplink data may be UL-SCH data, although the scope of embodiments is not limited in this respect.

In some embodiments, the uplink grant may be for uplink transmission in accordance with an enhanced mobile broadband (eMBB) technique, and the uplink data may be for uplink transmission in accordance with an ultra-reliable low latency communication (URLLC) technique. In some embodiments, the uplink data may become available to the MAC entity after reception of the uplink grant. In some embodiments, a priority of uplink data to be transmitted in accordance with the URLLC technique may be higher than a priority of uplink data to be transmitted in accordance with the eMBB technique.

Embodiments are not limited to transmission in accordance with eMBB techniques or URLLC techniques, however. One or more of the techniques, operations and/or methods described herein may be applicable to uplink data and/or uplink transmissions of any suitable type(s) (including but not limited to eMBB and/or URLLC), in some embodiments.

In some embodiments, an apparatus of a UE **102** may comprise memory. The memory may be configurable to store information related to RRC signaling. The memory may store one or more other elements and the apparatus may

use them for performance of one or more operations. The apparatus may include processing circuitry, which may perform one or more operations (including but not limited to operation(s) of the method **800** and/or other methods described herein). The processing circuitry may include a baseband processor. The baseband circuitry and/or the processing circuitry may perform one or more operations described herein, including but not limited to decoding of RRC signaling. The apparatus may include a transceiver to receive RRC signaling. The transceiver may transmit and/or receive other blocks, messages and/or other elements.

FIGS. **9-12** illustrates example operations and elements in accordance with some embodiments. FIG. **13** illustrates an example information element (IE) in accordance with some embodiments. It should be noted that the examples shown in FIGS. **9-13** may illustrate some or all of the concepts and techniques described herein in some cases, but embodiments are not limited by the examples. For instance, embodiments are not limited by the name, number, type, size, ordering, arrangement of elements (such as devices, operations, messages and/or other elements) shown in FIGS. **9-13**. Although some of the elements shown in the examples of FIGS. **9-13** may be included in a 3GPP LTE standard, 5G standard, NR standard and/or other standard, embodiments are not limited to usage of such elements that are included in standards.

In some embodiments, a "new immediate transmission" or proposed "new transmission" could refer to the next available UL-SCH resource for MAC PDU transmission. In a non-limiting example, in the subclause 5.4.5 in Rel-15 TS 38.321 v2.0.0 of the 3GPP standard, "new immediate transmission" or proposed "new transmission" could refer to the next available UL-SCH resource for MAC PDU transmission.

In a non-limiting example scenario, URLLC data arrival takes place after a UL grant for eMBB service has been received. In this case, the LCH serving the URLLC service may trigger the BSR. The UL-SCH resource allocated by the UL grant may be considered available, which in turn may prevent the UE **102** from triggering SR for the URLLC services as given below in the text and in FIG. **9**. In the non-limiting example **900** in FIG. **9**, the SR is not triggered by the URLLC data.

In the text below, and in some descriptions herein, the notation of a number followed by a ">" symbol may be used as part of a logic structure, a logic hierarchy, an organization of some operations/conditions, an outline of an implementation, a level of indentation, a structure that includes different levels of indentation, pseudo-code and/or other, although the scope of embodiments is not limited in this respect.

In such structures described herein, embodiments are not limited to the ordering, numbering and other aspects of the elements of the structures. In some embodiments, a structure may not include all elements described. In some embodiments, a structure may include one or more additional elements. In some embodiments, a structure may include one or more elements that are similar to one or more elements of a structure described herein.

In addition, usage of the word "shall" is also not limiting in the text below and in some descriptions herein. The word "shall" may be used in some standards (such as 3GPP standards and/or other) and may indicate mandatory behavior. Some of the operations, techniques and/or concepts described herein may be described in a similar manner. It is understood, however, that some embodiments may be based on similar operations, techniques and/or concepts that do not necessarily include such mandatory behavior and also may not necessarily be described with the word "shall." For instance, some embodiments may include an operation in which the MAC entity shall start a timer. Some embodiments may include an operation in which: the MAC entity starts the timer, the MAC entity may start the timer and/or other.

In some embodiments, the following and/or similar may be used:

The MAC entity shall:

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new transmission and the UL-SCH resources can accommodate the BSR MAC CE plus its subheader as a result of logical channel prioritization:

3> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

3> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs; 3> start or restart retxBSR-Timer.

2> if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if there is no UL-SCH resource available for a new transmission; or

3> if the MAC entity is configured with configured uplink grant(s) and the Regular BSR was triggered for a logical channel for which logicalChannelSR-Mask is set to false; or

3> if the UL-SCH resources available for a new transmission do not meet the LCP mapping restrictions (which may be described herein and/or included in subclause 5.4.3.1 of TS 38.321, although the scope of embodiments is not limited in this respect) configured for the logical channel that triggered the BSR:

4> trigger a Scheduling Request.

In some embodiments, UL-SCH resources are considered available if the MAC entity has an active configuration for either type of configured uplink grants, or if the MAC entity has received a dynamic uplink grant, or if both of these conditions are met. If the MAC entity has determined at a given point in time that UL-SCH resources are available, this need not imply that UL-SCH resources are available for use at that point in time.

In some embodiments, the following and/or similar may be used:

The MAC entity shall:

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission:

2> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

3> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

3> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some cases, to meet the delay requirements for the URLLC services, it may be important that such services be allowed to trigger SR instead of relying on the UL resources of the eMBB services. However, this may be used, in some cases, to avoid the frequent triggering of SR requests when there is UL-SCH resource available to transmit BSR.

In some embodiments, one or more techniques, operations and/or methods may be used for allowing the trigger of SR and also transmission of such SR for the URLLC services to meet the delay requirement. In some embodiments, URLLC services may be assigned a highest priority logical channel for DRB and only this logical channel can trigger the SR. In some embodiments, URLLC services may be assigned a high priority (and/or a highest priority) logical channel for DRB and this logical channel may trigger the SR.

In some embodiments, triggering of SR may be performed. The MAC may not necessarily recognize the URLLC or eMBB services. It may recognize the logical channel ID which is serving the different services. It may be up to the gNB **105** to configure a particular logical channel to meet the requirement of the service it is serving. Therefore, the gNB **105** may dedicate a particular logical channel ID to the UE **102** for the purpose of serving such services. In some cases, this may result in special treatment of the logical channel. For example, the regular BSR triggered by such logical channel can trigger SR if no UL resources are available in the numerology/TTI that it is allowed to use.

In some embodiments, the SR may be triggered based at least partly on a priority of the LCH. If a UL-SCH resource is available for transmission of MAC PDU, only the BSR triggered by the highest priority LCH for DRB can trigger the scheduling request provided the LCH is not allowed to use the available UL-SCH resource. The gNB **105** may optionally assign a highest priority for such logical channel if the UE **102** is using high priority services like URLLC. A potential consequence of this mechanism is that the UE **102** may both include BSR in the MAC PDU to be transmitted in the currently available UL resource and trigger SR to request UL grant for the high priority service in the particular scenario described above. In this case, it may not necessarily be guaranteed that the UE **102** receives the response to the SR. Therefore, the UE **102** may include BSR MAC CE in the MAC PDU for the new UL resource in UL-SCH if received even though it has already decided to include the BSR MAC in the MAC PDU to transmit in the previously available UL-SCH resource. The BSR may reflect the status of the buffer after the MAC PDU is built. In some embodiments, the following may be used.

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission:

3> if at least one Regular BSR was triggered for a highest priority logical channel for DRB for which logical channel SR masking (logicalChannelSR-Mask) is not setup and available UL-SCH resource is not allowed to be used by upper layers:

4> trigger a Scheduling Request.

3> else

4> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

4> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

4> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some embodiments, the following may be used.

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission:

3> if at least one Regular BSR was triggered for a highest priority logical channel for DRB for which logical channel SR masking (logicalChannelSR-Mask) is not setup and available UL-SCH resource is not allowed to be used by upper layers:

4> trigger a Scheduling Request.

3> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

3> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

3> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some embodiments, an information element (IE) may be defined in the configuration of logical channel to indicate a special LCH. The BSR triggered by such an LCH for DRB can trigger the scheduling request provided the LCH is not allowed to use any available UL-SCH resource. Such an LCH may be used to serve the URLLC services. In some embodiments, if the element "prioritizedSchedulingRequest" is set to TRUE, the LCH may triggers SR if a BSR is triggered. In some embodiments, if the element "prioritizedSchedulingRequest" is set to TRUE, the LCH always triggers SR if a BSR is triggered.

In some embodiments, an IE, including but not limited to a LogicalChannelConfig IE, may be used to configure the logical channel parameters. A non-limiting example of a LogicalChannelConfig IE **1300** is shown in FIG. **13**. Embodiments are not limited to the order, arrangement, type, size or other aspects of the elements shown in the LogicalChannelConfig IE **1300**. In some embodiments, the LogicalChannelConfig IE **1300** may not necessarily include all elements shown in FIG. **13**. In some embodiments, the LogicalChannelConfig IE **1300** may include one or more elements not shown in FIG. **13**. In some embodiments, the LogicalChannelConfig IE **1300** may include one or more elements that are similar to one or more elements shown in FIG. **13**.

In some embodiments, the following may be used.

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission:

3> if at least one Regular BSR was triggered for a logical channel for which prioritizedSchedulingRe quest is set and logical channel SR masking (logicalChannelSR-Mask) is not setup and available UL-SCH resource is not allowed to be used by upper layers:

4> trigger a Scheduling Request.

3> else

4> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

4> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

4> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some embodiments, the following may be used.

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission:

3> if at least one Regular BSR was triggered for a logical channel for which prioritizedSchedulingRe quest is set and logical channel SR masking (logicalChannelSR-Mask) is not setup and available UL-SCH resource is not allowed to be used by upper layers:

4> trigger a Scheduling Request.

3> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

3> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

3> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some embodiments, the BSR may be allowed to trigger the SR if the BSR was triggered by the LCH which is not allowed to use the available UL-SCH resources because it does not meet the criteria for lcp-allowedSCS and lcp-maxPUSCH-Duration associated with the UL-SCH resource. In some embodiments, the BSR may trigger the SR if the BSR was triggered by the LCH which is not allowed to use the available UL-SCH resources because it does not meet the criteria for lcp-allowedSCS and lcp-maxPUSCH-Duration associated with the UL-SCH resource. In some embodiments, the following may be used.

1> if the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

2> if UL-SCH resources are available for a new immediate transmission and are allowed to be used for the LCH that triggered the BSR:

4> instruct the Multiplexing and Assembly procedure to generate the BSR MAC CE(s);

4> start or restart periodicBSR-Timer except when all the generated BSRs are long or short Truncated BSRs;

4> start or restart retxBSR-Timer.

2> else if a Regular BSR has been triggered and logicalChannelSR-DelayTimer is not running:

3> if an uplink grant is not a configured grant; or

3> if the Regular BSR was not triggered for a logical channel for which logical channel SR masking (logicalChannelSR-Mask) is setup by upper layers:

4> trigger a Scheduling Request.

In some embodiments, an SR may be transmitted. In some cases, including some cases included in 3GPP standard TS 38.321, the triggered SR is cancelled if a BSR is included in the MAC PDU. For instance, from TS 38.321: "When an SR is triggered, it shall be considered as pending until it is cancelled. All pending SR(s) shall be cancelled and each respective sr-ProhibitTimer shall be stopped when a MAC PDU is assembled and this PDU includes a BSR which contains buffer status up to (and including) the last event that triggered a BSR (see subclause 5.4.5), or when the UL grant(s) can accommodate all pending data available for transmission." This may indicate that even if the SR is triggered by the LCH serving the URLLC service, it is possible that this SR could be cancelled before transmission if the UE **102** builds a MAC PDU and includes BSR before the next PUCCH resource for the SR.

Referring to FIG. **10** and FIG. **11**, non-limiting example scenarios are shown in which the SR triggered by such LCH are cancelled. The scenarios **1000** and **1100** illustrate non-limiting example scenarios in which triggered BSR or SR is cancelled. Note that in some cases, the delay K**2** may not meet the delay requirement for URLLC services and such cancellation of SR or BSR may be undesirable.

In some embodiments, when the UE **102** receives a UL grant and performs the LCP and decides which LCHs are selected to provide the available resources, the SR or BSR triggered by the LCH is not cancelled provided that this LCH did not meet the criteria for lcp-allowedSCS and lcp-maxPUSCH-Duration associated with the resource provided in the UL grant and this LCH also has highest priority or prioritizedSchedulingRequest is set to TRUE.

In some embodiments, the UE **102** may delay building the MAC PDU until the next PUCCH transmission opportunity for the triggered SR if there is enough time before the next UL-SCH transmission opportunity and it detects that the LCH for which the priority is set to highest or prioritizedSchedulingRequest is set to TRUE. A non-limiting example **1200** is shown in FIG. **12**. In the non-limiting example **1200** shown in FIG. **12**, the UE **102** may avoid cancellation of the BSR or SR, in some cases.

In some embodiments, a periodic BSR with smallest periodicity may be configured. This may cause the periodic BSR to be triggered frequently, in some cases. Only if the LCH, for which the priority is set to highest or prioritizedSchedulingRequest is set to TRUE, is allowed to trigger SR if the LCH has data available.

In some embodiments, a method of triggering SR by a LCH which is serving the URLLC services may be performed. In some embodiments, the LCH may be of highest priority for a DRB. In some embodiments, the LCH may be identified by an IE, for example "prioritizedSchedulingRe quest" is set to TRUE, when the LCH is configured. In some embodiments, the LCH may trigger a scheduling request if this LCH triggered a regular BSR, has no logical channel SR masking (logicalChannelSR-Mask) setup and is not allowed to use currently available UL-SCH resource for MAC PDU transmission. In some embodiments, a method may be performed of triggering SR by the LCH which triggered a BSR, is not allowed to use the available UL-SCH resources because the LCH does not meet the criteria for lcp-allowedSCS and lcp-maxPUSCH-Duration associated with the UL-SCH resource. In some embodiments, a method of triggering SR by the LCH may be performed. In some embodiments, a method of transmitting SR by an LCH which is serving the URLLC service may be performed. In some embodiments, the BSR or SR triggered by the LCH is not cancelled even if the UE **102** builds a MAC PDU including BSR provided that the LCH is not allowed to use currently available UL-SCH resource for MAC PDU transmission. In some embodiments, the UE **102** may delay building the MAC PDU until the next PUCCH transmission opportunity for the SR triggered by the LCH if there is enough time to build a MAC PDU before the next UL-SCH transmission opportunity.

In Example 1, an apparatus of a User Equipment (UE) may comprise memory. The apparatus may further comprise processing circuitry. The processing circuitry may support a medium access control (MAC) entity. The processing circuitry may be configured to decode radio resource control

(RRC) signaling from a Next Generation Node-B (gNB), wherein the RRC signaling allocates one or more logical channels to one or more logical channel groups (LCG) for uplink transmissions. The processing circuitry may be further configured to decode an uplink grant for uplink shared channel (UL-SCH) data transmission by the UE. The processing circuitry may be further configured to, if uplink data for one of the logical channels becomes available to the MAC entity, determine whether to trigger a regular buffer status report (BSR) to provide the gNB with information about uplink data volumes in the MAC entity. The processing circuitry may be further configured to, if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available UL-SCH data resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel of the uplink data: trigger a scheduling request to request UL-SCH data resources for a new transmission of the uplink data.

In Example 2, the subject matter of Example 1, wherein the processing circuitry may be further configured to determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions if: a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes a subcarrier spacing index associated to the uplink grant, wherein the allowed-SCSlist may be included in the RRC signaling; and a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant, wherein the maxPUSCH-duration may be included in the RRC signaling.

In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the processing circuitry may be further configured to determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions further if: a configuredGrantType1Allowed for the logical channel of the uplink data is set to true in case the uplink grant is a configured grant Type 1, wherein the configuredGrantType1Allowed may be included in the RRC signaling; and allowedServingCells for the logical channel of the uplink data includes cell information associated to the uplink grant, wherein the allowedServingCells may be included in the RRC signaling.

In Example 4, the subject matter of one or any combination of Examples 1-3, wherein the RRC signaling may include, for each logical channel: an allowed-SCSlist, and a maxPUSCH-duration.

In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the processing circuitry may be further configured to trigger the scheduling request if the logical channel of the uplink data is not allowed to use the available UL-SCH data resources because the logical channel of the uplink data does not meet criteria related to: an allowed subcarrier spacing of the available UL-SCH data resources; and a maximum PUSCH duration of the available UL-SCH data resources.

In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the processing circuitry may be further configured to determine to trigger the regular BSR if: the priority of the logical channel of the uplink data is higher than priorities of any logical channel containing available uplink data, for the logical channels of any of the LCGs; or for the logical channels of the LCG to which the logical channel of the uplink data belongs, none of the logical channels contains available uplink data.

In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the processing circuitry may be further configured to assemble a MAC protocol data unit (PDU) for transmission. The processing circuitry may be further configured to cancel all current pending SRs. The processing circuitry may be further configured to stop each respective sr-ProhibitTimer for the pending SRs at a later time when the MAC PDU is transmitted.

In Example 8, the subject matter of one or any combination of Examples 1-7, wherein the processing circuitry may be further configured to assemble a MAC protocol data unit (PDU) for transmission. The processing circuitry may be further configured to cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the uplink grant may be for uplink transmission in accordance with an enhanced mobile broadband (eMBB) technique. The uplink data may be for uplink transmission in accordance with an ultra-reliable low latency communication (URLLC) technique. The uplink data may become available to the MAC entity after reception of the uplink grant.

In Example 10, the subject matter of one or any combination of Examples 1-9, wherein a priority of uplink data to be transmitted in accordance with the URLLC technique may be higher than a priority of uplink data to be transmitted in accordance with the eMBB technique.

In Example 11, the subject matter of one or any combination of Examples 1-10, wherein the processing circuitry may be further configured to refrain from cancellation of the regular BSR or the triggered SR even if the UE builds a medium access control (MAC) protocol data unit (PDU) including the regular BSR, provided that the logical channel of the uplink data is not allowed to use available UL-SCH resources for transmission of the MAC PDU.

In Example 12, the subject matter of one or any combination of Examples 1-11, wherein the processing circuitry may be further configured to assemble a medium access control (MAC) protocol data unit (PDU) that includes the regular BSR. The processing circuitry may be further configured to cancel the regular BSR or the triggered SR at a later time when the UE transmits the MAC PDU that includes the regular BSR.

In Example 13, the subject matter of one or any combination of Examples 1-12, wherein the processing circuitry may be further configured to assemble a medium access control (MAC) protocol data unit (PDU) that includes the regular BSR. The processing circuitry may be further configured to cancel all current pending SRs and BSRs at a later time when the UE transmits the MAC PDU that includes the regular BSR.

In Example 14, the subject matter of one or any combination of Examples 1-13, wherein the UE may be arranged to operate in accordance with a new radio (NR) protocol.

In Example 15, the subject matter of one or any combination of Examples 1-14, wherein the apparatus may include a transceiver to receive the RRC signaling. The processing circuitry may include a baseband processor to decode the RRC signaling. The memory may be configured to store information related to the RRC signaling.

In Example 16, a non-transitory computer-readable storage medium may store instructions for execution by processing circuitry of a User Equipment (UE). The operations may configure the processing circuitry to decode an uplink grant for uplink shared channel (UL-SCH) data transmission by the UE. The operations may further configure the pro-

cessing circuitry to, if uplink data for a logical channel becomes available to the MAC entity: determine whether to trigger a regular buffer status report (BSR) based at least partly on whether a priority of the logical channel of the uplink data is higher than priorities of other logical channels. The operations may further configure the processing circuitry to, if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available UL-SCH data resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel of the uplink data: trigger a scheduling request to request UL-SCH data resources for a new transmission of the uplink data. The one or more LCP mapping restrictions may be based on: a subcarrier spacing index associated to the uplink grant, and a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant.

In Example 17, the subject matter of Example 16, wherein the operations may further configure the processing circuitry to determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions further if: a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes the subcarrier spacing index associated to the uplink grant; and a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to the PUSCH transmission duration associated to the uplink grant.

In Example 18, the subject matter of one or any combination of Examples 16-17, wherein the operations may further configure the processing circuitry to assemble a MAC protocol data unit (PDU) for transmission. The operations may further configure the processing circuitry to cancel all pending SRs triggered prior to assembly of the MAC PDU. The operations may further configure the processing circuitry to stop each respective sr-ProhibitTimer for the pending SRs when the MAC PDU is transmitted. The operations may further configure the processing circuitry to cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

In Example 19, an apparatus of a User Equipment (UE) may comprise memory. The apparatus may further comprise processing circuitry. The processing circuitry may support a medium access control (MAC) entity. The processing circuitry may be configured to decode radio resource control (RRC) signaling from a Next Generation Node-B (gNB). The RRC signaling may allocate one or more logical channels to one or more logical channel groups (LCG) for uplink transmissions. The processing circuitry may be further configured to, if uplink data for one of the logical channels becomes available to the MAC entity: determine whether to trigger a regular buffer status report (BSR) based at least partly on the logical channel for the uplink data. The processing circuitry may be further configured to, if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, trigger a scheduling request to request uplink shared channel (UL-SCH) data resources for a new transmission of the uplink data if: there are no UL-SCH data resources available for the new transmission; or if the MAC entity is configured with one or more configured uplink grants and a logicalChannelSR-Mask of the logical channel that triggered the regular BSR is set to false; or if UL-SCH data resources available for the new transmission do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel that triggered the BSR.

In Example 20, the subject matter of Example 19, wherein the processing circuitry may be further configured to decode an uplink grant for UL-SCH data transmission by the UE. The one or more LCP mapping restrictions may be based on: a subcarrier spacing index associated to the uplink grant; and a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

What is claimed is:

**1**. An apparatus of a user equipment (UE), the apparatus comprising: one or more processors coupled to a memory of the UE, wherein the one or more processors are configured to:

configure a medium access control (MAC) entity for buffer status reporting to provide a Next Generation Node-B (gNB) with information about uplink data volume in the MAC entity;

decode radio resource control (RRC) signaling from the gNB, wherein the RRC signaling indicates parameters for the buffer status reporting including an indication of one or more logical channels allocated one or more logical channel groups (LCGs); and

decode an uplink grant for uplink shared channel (UL-SCH) transmission by the UE, and

wherein the MAC entity is configured to:

trigger a regular buffer status report (BSR) if uplink data for one of the logical channels becomes available to the MAC entity and if the uplink data belongs to a logical channel with a higher priority than a priority of another logical channel containing other available UL data; and

if the regular BSR is triggered, trigger a scheduling request (SR) to request UL-SCH resources for a new transmission of the uplink data if a logical channel scheduling request (SR) delay timer is not running and if available UL-SCH resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel that triggered the regular BSR, and wherein the memory is configured to store the one or more LCP mapping restrictions configured for the logical channel.

**2**. The apparatus according to claim **1**, wherein the MAC entity is further configured to determine that the available UL-SCH resources meet the one or more LCP mapping restrictions if:

a set of allowed subcarrier spacing index values in an allowed list for the logical channel that triggered the regular BSR includes a subcarrier spacing index associated with the uplink grant, wherein the allowed list is indicated by the RRC signaling, and

a maxPUSCH-duration for the logical channel that triggered the regular BSR is larger than or equal to a physical uplink shared channel (PUSCH) transmission duration associated with the uplink grant, wherein the maxPUSCH-duration is indicated by the RRC signaling.

**3**. The apparatus according to claim **2**, wherein the one or more processors are further configured to determine that the available UL-SCH resources meet the one or more LCP mapping restrictions further if:

a configured Grant Type Allowed for the logical channel that triggered the regular BSR is set to true, the configured Grant Type Allowed indicated in the RRC signaling, and

allowed Serving Cells for the logical channel that triggered the regular BSR includes cell information associated with the uplink grant, the allowed Serving Cells indicated in the RRC signaling.

**4**. The apparatus according to claim **2**, wherein the RRC signaling includes, for each logical channel,

an allowed-SCSlist; and

a maxPUSCH-duration.

**5**. The apparatus according to claim **2**, wherein the MAC entity is further configured to:

trigger the scheduling request if the logical channel of the uplink data is not allowed to use the available UL-SCH resources because the logical channel of the uplink data does not meet criteria related to:

an allowed subcarrier spacing of the available UL-SCH resources, and

a maximum PUSCH duration of the available UL-SCH resources.

**6**. The apparatus according to claim **1**, wherein the MAC entity is further configured to further determine to trigger the regular BSR if for the logical channels of the LCG to which the logical channel of the uplink data belongs: none of the logical channels contains available uplink data.

**7**. The apparatus according to claim **1**, wherein the one or more processors are further configured to:

assemble a MAC protocol data unit (PDU) for transmission;

cancel all pending SRs triggered prior to assembly of the MAC PDU; and

stop each respective sr-ProhibitTimer for the pending SRs when the MAC PDU is transmitted.

**8**. The apparatus according to claim **1**, wherein the one or more processors are further configured to:

assemble a MAC protocol data unit (PDU) for transmission; and

cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

**9**. The apparatus according to claim **1**, wherein:

the uplink grant is for uplink transmission in accordance with an enhanced mobile broadband (eMBB) technique,

the uplink data is for uplink transmission in accordance with an ultra-reliable low latency communication (URLLC) technique, and

the uplink data becomes available to the MAC entity after reception of the uplink grant.

**10**. The apparatus according to claim **9**, wherein a priority of uplink data to be transmitted in accordance with the URLLC technique is higher than a priority of uplink data to be transmitted in accordance with the eMBB technique.

**11**. The apparatus according to claim **1**, wherein the one or more processors are further configured to:

refrain from cancellation of the regular BSR or the triggered SR even if the UE builds a medium access control (MAC) protocol data unit (PDU) including the regular BSR, provided that the logical channel of the uplink data is not allowed to use available UL-SCH resources for transmission of the MAC PDU.

**12**. The apparatus according to claim **1**, wherein the one or more processors are configured to:

assemble a medium access control (MAC) protocol data unit (PDU) that includes the regular BSR; and

cancel the regular BSR or the triggered SR at a later time when the UE transmits the MAC PDU that includes the regular BSR.

**13**. The apparatus according to claim **1**, the wherein the one or more processors are configured to:

assemble a medium access control (MAC) protocol data unit (PDU) that includes the regular BSR; and

cancel all current pending SRs and BSRs at a later time when the UE transmits the MAC PDU that includes the regular BSR.

**14**. The apparatus according to claim **1**, wherein the UE is arranged to operate in accordance with a new radio (NR) protocol.

**15**. The apparatus according to claim **1**, wherein:

the apparatus includes a transceiver to receive the RRC signaling,

the one or more processors includes a baseband processor to decode the RRC signaling, and

the memory is configured to store information related to the RRC signaling.

**16**. A non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of a User Equipment (UE), the operations to configure the one or more processors to:

decode an uplink grant for uplink shared channel (UL-SCH) data transmission by the UE;

if uplink data for a logical channel becomes available to the MAC entity, determine whether to trigger a regular buffer status report (BSR) based at least partly on whether a priority of the logical channel of the uplink data is higher than priorities of other logical channels;

if the regular BSR is triggered and a logical channel scheduling request (SR) delay timer is not running, and if available UL-SCH data resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel of the uplink data:

trigger a scheduling request to request UL-SCH data resources for a new transmission of the uplink data,

wherein the one or more LCP mapping restrictions are based on:

a subcarrier spacing index associated to the uplink grant, and

a physical uplink shared channel (PUSCH) transmission duration associated to the uplink grant.

**17**. The non-transitory computer-readable storage medium according to claim **16**, the operations to further configure the one or more processors to:

determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions further if:

a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes the subcarrier spacing index associated to the uplink grant, and

a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to the PUSCH transmission duration associated to the uplink grant.

**18**. The non-transitory computer-readable storage medium according to claim **16**, the operations to further configure the one or more processors to:

assemble a MAC protocol data unit (PDU) for transmission;

cancel all pending SRs triggered prior to assembly of the MAC PDU;

stop each respective sr-ProhibitTimer for the pending SRs when the MAC PDU is transmitted; and

cancel all BSRs triggered prior to assembly of the MAC PDU when the MAC PDU is transmitted.

**19**. A user equipment (UE), the comprising:

one or more memory mediums; and

one or more processors coupled to the one or more memory mediums, wherein the one or more processors are configured to cause the UE to:

configure a medium access control (MAC) entity for buffer status reporting to provide a Next Generation Node-B (gNB) with information about uplink data volume in the MAC entity;

decode radio resource control (RRC) signaling from the gNB, wherein the RRC signaling indicates parameters for the buffer status reporting including an indication of one or more logical channels allocated one or more logical channel groups (LCGs); and

decode an uplink grant for uplink shared channel (UL-SCH) transmission by the UE, and

wherein the MAC entity is configured to:

trigger a regular buffer status report (BSR) if uplink data for one of the logical channels becomes available to the MAC entity and if the uplink data belongs to a logical channel with a higher priority than a priority of another logical channel containing other available UL data; and

if the regular BSR is triggered, trigger a scheduling request (SR) to request UL-SCH resources for a new transmission of the uplink data if a logical channel scheduling request (SR) delay timer is not running and if available UL-SCH resources do not meet one or more logical channel prioritization (LCP) mapping restrictions configured for the logical channel that triggered the regular BSR, and wherein the one or more memory mediums are configured to store the one or more LCP mapping restrictions configured for the logical channel.

**20**. The UE according to claim **19**, wherein the one or more processors are further configured to:

determine that the available UL-SCH data resources meet the one or more LCP mapping restrictions further if:

a set of allowed subcarrier spacing index values in an allowed-SCSlist for the logical channel of the uplink data includes the subcarrier spacing index associated to the uplink grant, and

a maxPUSCH-duration for the logical channel of the uplink data is larger than or equal to the PUSCH transmission duration associated to the uplink grant.

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